Belgian Road Research Centre
Together for sustainable roads

Connected & Autonomous Vehicles and road infrastructure

State of play and outlook

Synthesis

SE 51

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Synthesis SE 51

Connected & Autonomous Vehicles and road infrastructure

State of play and outlook

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Disclaimer

This text is based on a variety of external sources and comments and feedback from the members of the working group. In some cases, existing knowledge or experience gained during pilot projects is used or referred to. Many assumptions are merely a reflection of expectations or estimates based on the knowledge of the members of the working group and other literature. Today, in the current state of science, there is no conclusive proof for any of these assumptions. In any case, we will have to wait and see how the technology of self-driving vehicles will evolve and what impact this will have on the organisation of transport in general and on infrastructure in particular. Consequently, neither the members of the working group nor BRRC can be held liable in any way for decisions taken based on this text.

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Message to the reader

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Chapter 1
Introduction

The **technological developments** around self-driving or autonomous vehicles (CAV, connected & autonomous vehicles) go at lightning speed. Are all those involved ready for a successful and safe introduction? How can vehicles with **a different degree of autonomy** jointly make safe use of the **available road infrastructure**?[1]

The **infrastructure component** plays a role in the developments of CAV. However, in many areas it is unclear how far the role of **road infrastructure** extends. Underlying questions are:

- What are the consequences of CAV on the existing road infrastructure?
- What opportunities does CAV offer for the road infrastructure?
- Within which timeframe should the road infrastructure be developed?
- What distinction in terms of road infrastructure can be made between connected vehicles and autonomous vehicles?
- What modifications are needed for a safe mix of CAV and other vehicles (non-CAV)?
- What is clear and what is still uncertain?
- When designing and building road infrastructure today, are there any recommendations or points of attention that simplify the roll-out of automated vehicles in the future?

By studying these sub-questions in a **working group** led by BRRC with external members, BRRC wishes to investigate[2] the developments concerning CAV and the role of the infrastructure component.

This report provides insight into the possible consequences for road infrastructure and road authorities. The report is the result of literature research by BRRC and fascinating discussions on relevant themes with the active working group members: theme ‘motorways’, theme ‘urban mobility’ and theme ‘shuttles’.

The main body of the report starts with **chapter 2** on a number of contextual topics:

2.1 Description of CAV
2.2 Objectives
2.3 SAE levels
2.4 Roll-out of CAV and obstacles

Subsequently, **chapter 3** deals in concrete terms with the relationship between CAV and infrastructure. The themes on which sufficient information was found were worked out in the working group. The themes are as follows:[3]

3.1 Physical infrastructure and digital infrastructure
3.2 Motorways
3.3 Roads in an urban environment (Urban Mobility)
3.4 Shuttles

Chapter 4 gives an overview of the main points of this study. This chapter also contains the conclusions on possible consequences for road infrastructure and road authorities. These conclusions are likely to apply several years after the publication of this report.

[1] SAE levels:
SAE L0 = No automation,
SAE L1 = Driver assistance,
SAE L2 = Partial automation,
SAE L3 = Conditional automation,
SAE L4 = High automation,
SAE L5 = Full automation.
See § 2.3 SAE levels.

[2] The study was financed from BRRC's own resources. The BRRC Programme Committee supports this initiative. See *https://brrc.be/en/aboutbrrc*.

[3] At the time of writing this report, there was insufficient information on roads outside built-up areas (with the exception of motorways).

We will discuss both the **bigger picture** and the **no regret** measures in the field of road infrastructure. The structure of the chapter:

4.1 Introduction
4.2 (Un-)certainty and complexity
4.3 Societal developments and policy
4.4 Road infrastructure

Chapter 5 provides background information, including an overview of regulations, European test sites and living labs, and definitions and abbreviations.

Chapter 2
Context of CAV

2.1 Description of CAV

2.1.1 Connected, autonomous

In our working group we used the short but powerful term CAV, for **connected & autonomous vehicles**. It is a collective term for vehicles which partly or completely assist the driver in carrying out the task of driving on the road[4].

A **connected vehicle** can be described as a vehicle with technology that enables it to communicate and exchange information wirelessly with other vehicles, infrastructure, other devices outside the vehicle and external networks (Society of Motor Manufacturers and Traders [SMMT], 2017). It is possible to 'update' connected vehicles if, for example, software needs to be updated or new rules need to be implemented (Harari, 2018). Connected vehicles are not necessarily autonomous[5].

An **autonomous vehicle** is a vehicle that can drive itself without human intervention. Several alternative terms are in use: self-driving car, robot car, driverless car. From a technological point of view, autonomous vehicles are equipped with all kinds of sensors that allow the position of the vehicle on the road to be known and the immediate surroundings of the road to be recognised.

The **degree of autonomy** is standardly indicated by the SAE level[6], a classification system developed by the organisation SAE International (a body for standardisation in the automotive industry).

Significant progress in terms of safety, mobility, emissions, etc. is expected if autonomous vehicles are also connected to other vehicles and road infrastructure[7]. Driver assist systems (ADAS) in autonomous vehicles can help prevent human errors and in some cases reduce severity. Infrastructure managers can contribute to that progress by providing connected infrastructure and allowing vehicles, infrastructure and other systems to exchange information.

For automobile manufacturers, connected and autonomous vehicles are not an end in themselves. Their primary goal is to develop safer and more environmentally friendly vehicles. In addition to classic automobile manufacturers, numerous technology companies are also heavily involved in the development of technology for self-driving vehicles.

The developments concerning connected and autonomous vehicles are, for the time being, two **parallel developments**. The information that vehicles receive today (usually via sensors) serves mainly to inform and encourage the human driver to behave in a certain way, but is currently not used, or only to a limited extent, to actively intervene in the behaviour of the vehicle. Autonomous vehicles, by contrast, allow for intervention in the behaviour of the vehicle based on the situations detected by the vehicle itself or – in the case of connected vehicles – information received by the vehicle from external sources.

4 The notion 'on the road' is important for the focus of the working group. Autonomous vehicles that can take off vertically and land or autonomous ships are not included in the reflection.

5 § 3.3.7 Digital infrastructure and services.

6 § 2.3 SAE levels.

7 However, UN/ECE Regulation No 79 (2008) (Introduction) does not currently allow the steering of a vehicle to be based on signals coming from outside the vehicle. According to the Geneva Convention (Art. 4) (Geneva Convention on Road Traffic, 1949), a driver must be a person.

For **European road authorities** (CEDR) the focus is shifting towards connected vehicles. The information that these vehicles register and transmit – via their connectivity – can provide road authorities with interesting information about the state of the infrastructure and enable them to better plan interventions and maintenance or organise traffic management using real-time information. Autonomous vehicles not only offer **opportunities** (road safety, mobility) but also involve **risks** (complexity, legal aspects)[8].

8 § 2.2 Objectives.

In addition, we can state the following about CAV:

- a CAV may have any form of **motorisation** (combustion engines, electric motors, hydrogen, etc.);
- a CAV may be either a private vehicle, a shared vehicle or a form of public transport;
- a CAV may be a vehicle for the transport of persons or goods. These are vehicles of different sizes.

Outside the direct scope of our report on CAV are 'connected' pedestrians, cyclists and micromobility (steps and similar means of transport). These modes can also be connected at a later stage and become detectable for infrastructure and other road users.

2.1.2 Automated

The code of conduct of the Federal Public Service Mobility and Transport, entitled 'autonomous vehicles, code of conduct for testing in Belgium', defines an **automated vehicle** and a **fully automated vehicle**[9] (Federal Public Service Mobility and Transport [Federal Public Service Mobility and Transport], 2016). These definitions refer to the UN/ECE regulations (Regulation No 79 UN/ECE, 2008).

9 § 5.3 Testing: test sites & Living Labs (EU).

The code of conduct provides guidelines for organisations wishing to carry out tests with technologies for driver assistance systems and automated vehicles on public roads or in other public places in Belgium.

An **automated vehicle** is a vehicle in which a driver has to be seated, ready to take back control at all times. However, in certain situations, the vehicle may provide an 'automatic mode' so that the driver does not need to be involved in steering and may perform other tasks.

A **fully automated vehicle** means a vehicle in which a driver is no longer required. The vehicle is designed so that it can safely undertake a journey without the intervention of a driver, in all traffic, road and weather conditions in which a skilled human driver can drive a vehicle[10].

10 The UNECE WP Automated / Autonomous and Connected Vehicles (GRVA) is working on functional requirements and evaluation methods for these new technologies in vehicles.

ACEA (European Automobile Manufacturers Association) distinguishes between assisted driving, automated driving and autonomous driving. The following figure shows the differences:

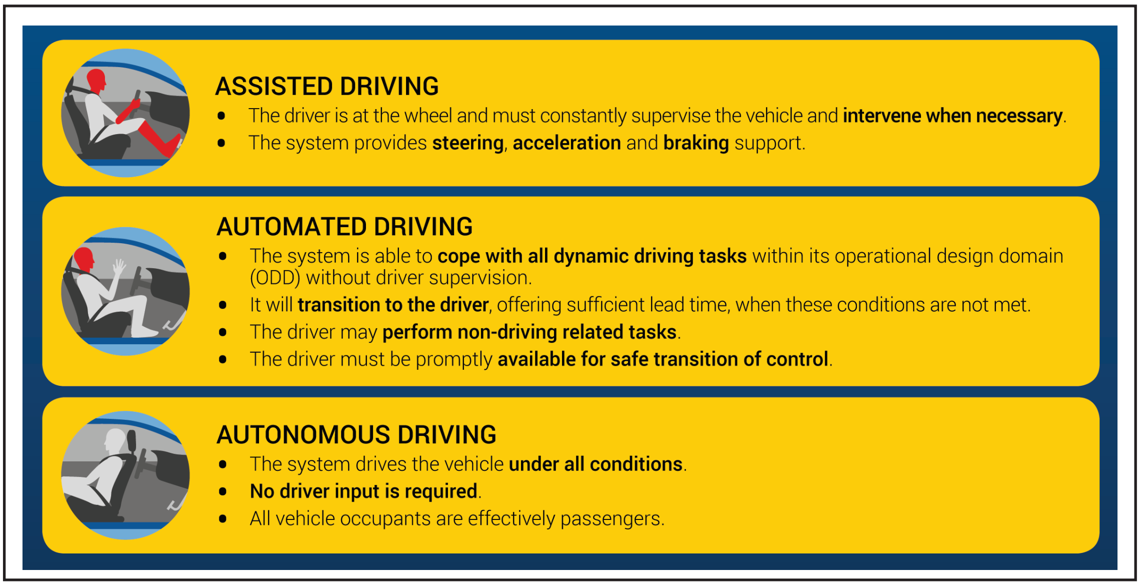

Figure 2.1 – *Levels of automated driving (European Automobile Manufacturers Association [ACEA], 2019, p. 2)*

So there are different terms in use for the same idea. However, there is a **common denominator**, indicating the level of automated driving for vehicles on roads: the **SAE levels** of SAE International[11].

[11] § 2.3 SAE levels.

2.1.3 Advanced Drivers Assistance Systems (ADAS)

Research and development of the vehicle industry towards safer vehicles focuses on supporting the driver while driving his vehicle. The support systems can then be picked up by the regulator. Safety systems that prove to be efficient will be subject to harmonised minimum functional requirements and, over time, will also be made mandatory under vehicle homologation regulations.

The list of systems is long, and different names are used for the same type of systems. Some of the best known systems:

ABS	Anti-lock Braking System	System that prevents wheels from locking under heavy braking
AEBS	Advanced Emergency Braking System	System capable of detecting a potential forward collision and activating the vehicle's braking system to decelerate the vehicle with the aim of preventing or reducing a collision
ACC[12]	Adaptive Cruise Control	System that controls the speed and tracking distance in relation to the previous vehicle
DAS	Driver Alert Systems	System that detects signs of a drowsy or impaired driver
ISA	Intelligent Speed Adaptation	System that ensures that the vehicle speed does not exceed a safe or legally allowed speed
LDWS[13]	Lane Departure Warning System	System that warns the driver when the vehicle starts to leave its driving lane
	Park Assist	Parking assistance system for parking/searching for free parking spaces

Table 2.1 – *Some common ADAS systems*

[12] The term Advanced Cruise Control is also used.

[13] Also in use:
Lane Keeping Assistance (LKA);
Lane Departure Warning (LDW).

All these systems are designed to **support** the human driver in his or her driving task or to detect and overcome potentially unsafe situations. Although some of these systems can take over the driving task from the driver in certain circumstances, the responsibility for driving still lies entirely with the (human) driver today.

In the course of 2022, the European Regulation 2019/2144[14] will enter into force. According to this regulation, from this date new vehicles must be equipped with a number of advanced vehicle systems (e.g. ISA, incident data recorder, fatigue alert, etc.).

[14] Regulation (EU) 2019/2144 (2019) on type-approval requirements for motor vehicles and their trailers, and systems, components and separate technical units intended for such vehicles, as regards their general safety and the protection of vehicle occupants and vulnerable road users.

Figure 2.2 – *New safety features in your car (European Commission [EC], n.d.)*

2.1.4 Driver

With regard to ADAS we speak of supporting the human driver. If we are talking about autonomous vehicles, is there still a driver?

The Geneva Convention (Geneva Convention on Road Traffic, 1949) gives a definition of a **driver**, and in a few articles indicates a number of important tasks for drivers (see table 2.2).

The traffic regulations of international origin were originally tailored to cars with drivers. Autonomous cars do not have a driver but do have occupants or users. This means that **international treaties** have to be **amended** (Vellinga & Vellinga, 2019).

article 4	Driver means any person who drives a vehicle, including cycles, or guides draught, pack or saddle animals or herds or flocks on a road, or who is in actual physical control of the same.
article 7	Every driver, pedestrian or other road user shall conduct himself in such a way as not to endanger or obstruct traffic; he shall avoid all behaviour that might cause damage to persons, or public or private property.
article 8.1	Every vehicle or combination of vehicles proceeding as a unit shall have a driver.
article 8.5	Drivers shall at all times be able to control their vehicles or guide their animals. When approaching other road users, they shall take such precautions as may be required for the safety of the latter.
article 10	The driver of a vehicle shall at all times have its speed under control and shall drive in a reasonable and prudent manner. He shall slow down or stop whenever circumstances so require, and particularly when visibility is not good.

Table 2.2 – *Geneva Convention (Geneva Convention on Road Traffic, 1949), definition of a driver*

2.1.5 CAV applications

Systems of a CAV are aimed at **numerous applications**. The end of the possibilities in the field of infotainment, safety, diagnostics, navigation and payment services does not yet seem to be in sight. Information and services are in full development.

With the **Directive 2010/40/EU** (2010) also called the European ITS Framework Directive, Europe identifies a number of priority areas and underlying actions to which Intelligent Transport Systems should contribute (e.g. European multimodal travel information services, real-time traffic information services, road safety related traffic information, etc.). When further developing specifications, applications and services, one of the principles is that the characteristics of existing national infrastructures should be taken into account.

Within the **BRRC working group** on CAV, however, it is not the intention to pay extensive attention to all systems and services that can be mounted to a connected vehicle. Rather, it concerns the interaction between automated vehicles and the **physical road infrastructure** and any useful modifications to this infrastructure.

In all probability, CAV will receive a large part of the information about physical infrastructure via digital systems. It is important that these digital systems (**digital infrastructure**) give a correct representation of the physical reality (road course, applicable traffic rules, other information). The Commission Delegated Regulation (EU) 2015/962 (2015) describes what information (in terms of infrastructure and traffic information) should be made available digitally and what the requirements are for updating this information. In the design, construction and maintenance of roads and road equipment, this will become an important point of attention (updating of so-called static road data).

This report focuses on private and public vehicles. These may be vehicles in individual or shared ownership, and vehicles offering a taxi or bus service (such as the shuttles tested nationally and internationally). In addition to passenger transport, we also pay attention to freight transport.

2.2 Objectives

For automobile manufacturers, self-driving vehicles are not an end in themselves. The research and development of self-driving vehicles is mainly driven by the pursuit of **zero-incident** and **zero-emission** vehicles. Because analysis of traffic accidents shows that the driver is an important factor, many developments focus on systems that simplify or take over (part of) the driver's tasks. In the most far-reaching view, this indeed leads to vehicles functioning without human intervention (SAE L4 and SAE L5)[15].

15 § 2.3 SAE levels.

The European Union wishes to become a world leader in the deployment of safe systems for automated mobility, increasing road safety and efficiency, combating congestion, reducing energy consumption and emissions from transport, and gradually phasing out fossil fuels (European Parliament Resolution of 15 January 2019, 2019).

This is the outline of objectives in the field of CAV. By means of a brief study of the literature, these objectives can be refined into **motives**:

- economic prosperity;
- road safety;
- congestion;
- mobility;
- use of space;
- energy efficiency & environmental friendliness;
- road capacity.

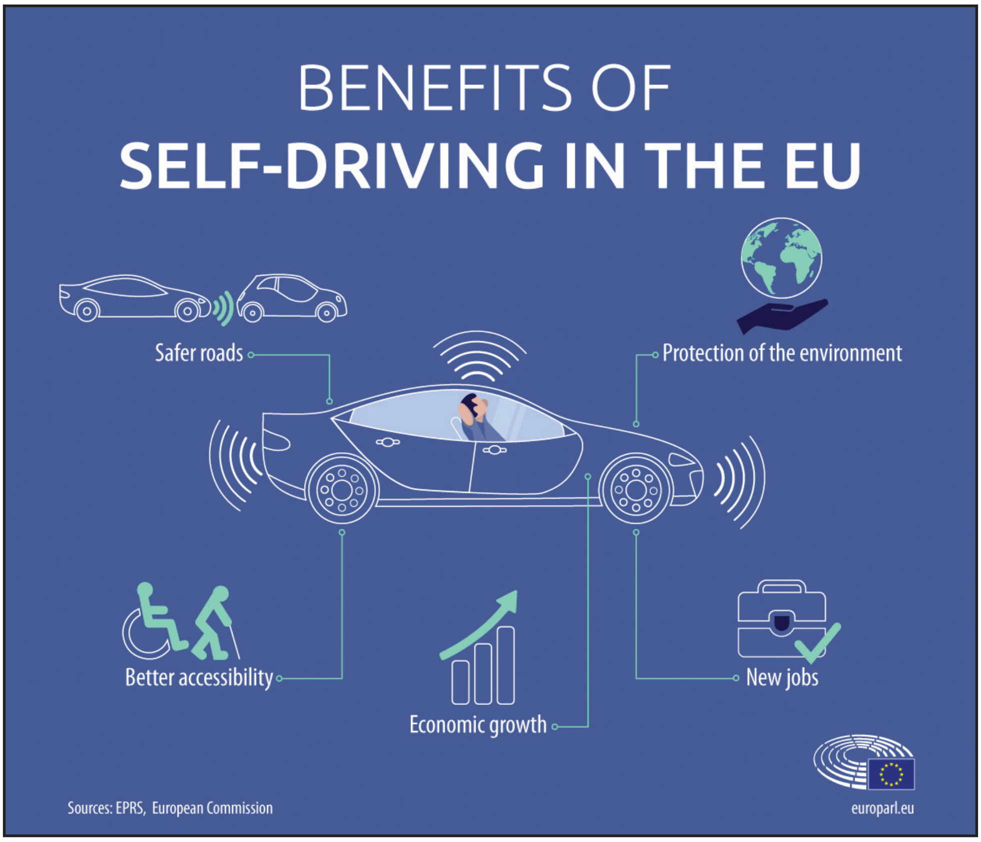

Figure 2.3 – *Benefits of self-driving vehicles in the EU, according to EPRS / European Commission ("Self-driving cars in the EU", 2019)*

Insight into the motives to allow connected and autonomous vehicles on public roads is useful to identify the link between CAV and road infrastructure. The **feasibility** of the objectives and motives is highly dependent on outlined policy, on consultation and cooperation between the various stakeholders, and on clear choices that take account of societal wishes and needs.

The promise of better mobility, less space occupancy and energy efficiency are not only linked to technological developments, but also depend on **societal choices** (e.g. the promotion of shared vehicles, high-performance public transport, scenarios to phase-out fossil-fuel vehicles and the availability of sufficient 'clean' electricity) (Morlion, 2018).

2.2.1 Economic prosperity

The EU considers it essential for the European industry that digital opportunities in terms of technological innovations (internet of things, 5G, cloud computing, data analysis, robotics) are quickly and maximally exploited. In the context of overall prosperity, this should ensure that Europe remains competitive in the medium and long term. The EU identified CAV as a priority topic to increase the **competitiveness** of European industry (European Commission [EC], 2016a)[16].

[16] The European Commission speaks of 'competitiveness'. This means that the EU remains competitive, takes or maintains a leading position, and remains at the top of the R&D field.

Member States see the potential of autonomous vehicles and estimate the economic and social benefits. For example, in former Member State the United Kingdom, SMMT (The Society of Motor Manufacturers and Traders Limited) expects that developments in the field of self-driving vehicles will create a large number of new jobs by 2030 (320 000 new jobs, of which 25 000 in vehicle production). Between 2014 and 2030, they also expect CAV to contribute to 2 500 **fewer fatalities** and 25 000 fewer **serious accidents**. These persons will then not be withdrawn from the labour market (SMMT, 2017).

The **automotive industry** also sees enormous potential in the self-driving car. In absolute figures, the automotive industry is an industry with high investments. The distribution of these investments varies from one continent or country to another, with some continents or countries adopting a dynamic approach and investing heavily in the development of autonomous vehicles. In other countries, there are different emphases. By way of illustration, according to the German *Verband der Automobil-industrie*, in the period 2019-2022 the German automotive industry is investing approximately €18 billion in digitisation, connectivity and technology for self-driving vehicles, while in the same period €40 billion is being invested in the development of electrically propelled vehicles (Redactie Automobiel Management, 2019b).

Furthermore, companies (outside the taxi sector) see a great future for **robotaxis**, which no longer require a driver. As a result, the traditional taxi sector is facing new competition. Organisations like Uber and Lyft invest a lot of money in the development. However, according to American research, the profitability of robotaxis compared to traditional taxis is still questionable (Van Wijngaarden, 2019b).

Last but not least, the **economic value of driving time** may change with the introduction of CAV. The travel time as a passenger of a CAV can be used differently and perhaps more pleasantly or economically useful than the travel time as a driver. People may be less concerned about longer journeys, which may lead to longer travel distances (Leeb, 2019).

2.2.2 Road safety

Driving safety experts expect the number of traffic accidents to fall substantially if autonomous vehicles take over all of the driver's tasks. Based on statistical accident data, the **potential** is enormous: about 90 % of accidents are somehow linked to a human factor (Treat et al., 1979). However, certain studies warn against overly positive expectations (Dutch Safety Board, 2019; International Transport Forum [ITF], 2018; Robinson, Wallbank & Baig, 2017).

During the transition period, there are two challenges to make effective gains in terms of road safety:

- Firstly, the introduction of all kinds of advanced vehicle systems is changing the role of the driver and is accompanied by new and as yet insufficiently known safety risks (Dutch Safety Board, 2019). Accompanying measures should address these risks.
- Secondly, there is uncertainty about the composition mix of vehicles (autonomous of various SAE levels and non-autonomous) in the fleet[17].

[17] It is certain that there will be a mix, called "mixed traffic", for decades to come. Estimates range from 30 to 40 years, due to the long service life of trucks and military vehicles that remain in service significantly longer (Conference of European Directors of Roads [CEDR], n.d.).

The intention of the improvements through the introduction of advanced vehicle systems and autonomous vehicles of higher levels of automation is obviously a positive one: a net improvement in safety. Introductions of systems for which there are questions or concerns in this respect can be reconsidered.

Elements with a direct effect on improved road safety through CAV are the ability to perform different tasks simultaneously and the faster reaction of the vehicle, which allows the vehicle to slow down, stop or change trajectories more quickly.

It also makes it possible to ensure that a supporting system can actively **intervene on the driving speed** and prevent inappropriate speeds. The road authorities have an important role to play in this respect: information on the speed limit must be correct and up to date (cf. digital infrastructure, traffic signs). In a scenario where all systems are connected, the maximum allowed speed can be dynamically adapted to the circumstances (weather conditions, incidents, traffic density, etc.). This can contribute to the credibility and acceptance of speed limits.

There may also be effects that **indirectly** contribute to a more traffic-safe system. For example, vehicles that can park themselves based on information about the availability of parking spaces. This results in less search traffic (direct effect), with a more constant driving speed (indirect effect).

The road safety potential is also related to the **level of automation**. Some organisations still have reasonable doubts as to whether the promising safety perspectives will be fully realised. The number of traffic accidents resulting from inappropriate behaviour may decrease. However, there is also a risk that **normally careful** drivers will become more involved in accidents, especially when they have to take control of the vehicle in emergency situations (ITF, 2018).

Environmental, comfort and mobility improvements seem to be a major driver for AD and ITS developments, together with the expected purely economic benefits (Lindström et al., 2018). For example, research from the Netherlands argues that four groups of ADAS have a substantial potential to reduce harm: Automatic Emergency Brake, Lane Change Assist/Blind Spot Monitoring, Lane Keep Assist and Park Assist. Together, in a realistic scenario, they reduce damage by 23 % (VMS/Insight, 2019).

One aspect that requires special attention is the ability to **understand or estimate** how the autonomous vehicle functions. If the driver no longer has to perform certain tasks himself, this can lead to reduced situational awareness (§ 2.4). This is when the driver does not know exactly what the system can do or when he himself still has to intervene ("I-DREAMS project", n.d.; Martens, 2014)[18].

Especially in the transitional situation where a self-driving vehicle in a problematic situation hands over the steering to a human driver, there is a chance that the human driver will need some time to correctly assess the traffic situation and focus on his driving task. Up to SAE Level 4, the driver remains responsible for tasks that are too complex for the advanced vehicle systems to handle correctly. Combined with **declining driving experience** (de-skilling), there is a high probability that taking over a driving task by a human driver will not be done quickly or correctly enough (ITF, 2018).

An important issue in the introduction of CAV is the improvement of the road safety of vulnerable, **active road users**.

- Pedestrians, cyclists and motorised two-wheelers remain non-automated road users for the time being. At best, they are connected (US Department of Transportation [DOT], n.d.)[19].
- Without specific attention, they would not be able to benefit directly or to the same extent as car and truck occupants from AD and ITS technology.
- The revised General Safety Regulation of the European Parliament and the European Council indicates that Vulnerable Road Users (VRU) should be taken into account and imposes minimum standards for the recognition of VRU (Regulation [EU] 2019/2144, 2019).
- It is best to ensure that the attention of active road users does not decrease during their journey, if they assume that the CAV will notice them anyway and adjust their road behaviour accordingly. Road safety in specific situations could decline if the CAV has to brake unexpectedly or deviate from its normal trajectory.

The traffic behaviour of pedestrians and cyclists with respect to cars often depends on **visual communication** between the different road users and the expression of intentions.

- There are experiments in which self-driving vehicles successfully detect cyclists and pedestrians and act accordingly (TED, 2015).
- Generally, algorithms find it difficult to correctly predict the behaviour of non-automated road users and to take the right action (Van Schagen, van der Kint & Hagenzieker, 2017). Incidentally, this is not exclusive to algorithms; human drivers can also have difficulty estimating human behaviour (unexpected movements).
- There is a lot of recent research into finding solutions for (unexpected) human behaviour (European Telecommunication Standards Institute [ETSI], 2019; Kunert et al., 2018; Mannion, 2019).

On the other hand, it is also important for **cyclists and pedestrians** to know that an approaching driver noticed them before, for example, deciding to cross a road. Between self-driving vehicles and non-automated road users, this communication is lost and the behaviour of these road users may change. On the basis of research, it is estimated that in 10 % of road fatalities in Europe – mainly accidents involving cyclists or motorcyclists – no motor vehicles, which can be automated, are involved (either as victim or as the other party) (Lindström et al., 2018).

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Various studies on this topic are underway, for example:
- IMOB Hasselt participated in the European Horizon 2020 project I-Dreams. This project sets up a platform to define, develop, test and validate a 'Safety Tolerance Zone' to prevent drivers from getting too close to the limits of an unsafe operation by reducing risks in real time and after the journey.
- The University of Twente compares several assistance systems via a Virtual Reality lab and a driving simulator, and looks at the design side of automated driving.
- TNO uses an instrumented vehicle, a driving simulator, videos and practical observations to measure human behaviour. They look at the interaction between the motorist and in-vehicle technology, but also how other people (such as motorists, cyclists and pedestrians) react to people in a (partly) automatically driving car.

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However, this is also evolving: the first tests with autonomous motors have taken place. See *www.youtube.com/watch?v=XMuMoZIVYqs* (Alpha SQUAD official, 2018).

2.2.3 Congestion

A much-discussed topic is the contribution that CAV could make to reducing congestion. The conclusion may be that it is uncertain whether congestion is decreasing. Several studies suggest that the CAV will even lead to more congestion.

The introduction of CAV (and in particular autonomous vehicles) may lead to **conflicting effects**.

On the one hand, there will be **additional free capacity** because autonomous vehicles can drive closer to each other (Friedrich, 2015)[20]. On the other hand, there is scientific evidence for the existence of a **latent transport demand**[21].

One point of attention is the idea of giving some population groups who are not allowed to drive a car themselves (such as young people without a driving licence or older people who can no longer drive) access to CAV. There is also potential for the use of autonomous vehicles in areas less easily accessible by public transport (e.g. rural areas).

Research also shows the importance of the debate on private ownership of a self-driving car and **sharing systems**. The implementation of appropriate policies is crucial to contain the consequences of the roll-out of CAV. A strong focus on sharing systems of autonomous vehicles can significantly reduce the number of vehicles. Simulations show that it would be possible to meet all mobility requirements within a city with only one sixth or one seventh of its current fleet (International Transport Forum [ITF], 2015; Leeb, 2019)[22].

The **question remains** how the use of autonomous taxis, autonomous private vehicles, 'traditional' public transport and active road users will develop, and what this means for **public space planning** (e.g. occupancy in a general sense, or specifically for e.g. reserved lanes for buses).

Swiss research studied the **cost component** (in addition to travel time, reliability and comfort, an important aspect of providing a transport service)[23]. This research distinguishes between urban and regional on the one hand, and autonomous and non autonomous on the other, and provides an insight into future relationships (Bösch, Becker, F., Becker, H. & Axhausen, 2018).

The following figure from the study shows how the cost component can be interpreted[24]:

- **Without automation**, the private car has the lowest operating cost per passenger kilometre (except regional train services)
  - because of the paid driver, taxi services are considerably more expensive;
  - city buses and regional railways operate at a similar cost per passenger kilometre as passenger cars.
- The picture **changes substantially with the automation** of vehicles
  - the costs of passenger cars and train services change marginally;
  - thanks to autonomous driving technology, taxi services and buses can be used at significantly lower costs, even cheaper than passenger cars;
  - in an **urban environment**, taxis become cheaper than conventional buses, but they remain more expensive than automated buses;
  - in **regional environments**, defined as suburban journeys, autonomous taxis and buses become cheaper than private vehicles and train services.

[20] In a scenario on a motorway at 80 km/h where the time between 2 vehicles is 1.15 sec (in the case of human drivers), the occupancy – if only self-driving passenger cars with 0.5 sec time between 2 vehicles – can increase from 2 200 to 3 900 vehicles/hour (Friedrich, 2015).

[21] Latent transport demand is the phenomenon where total traffic increases as road capacity increases. People, before the capacity expansion, staying at home or choosing a different route or mode of transport or a different time of day for their trip, cause the new traffic. The extent to which new traffic arises in response to capacity expansion can be expressed in terms of elasticities. Various scientific studies provide evidence for the existence of this so-called latent demand for road infrastructure. Estimates of elasticity range from about 0.2 in the short term to 0.8 in the long term (Dunkerley, Whittaker, Laird & Daly, 2018; Verrips, Hoen et al., 2016).

[22] § 3.3.4 Sharing systems.

[23] The examined cost components: overhead and vehicle operations, salaries, fuel, cleaning, parking and tolls, tax, insurance, depreciation, interest, maintenance and wear.

[24] The following costs are included in the comparison: overhead & vehicle operations, salaries, fuel, cleaning, parking & tolls, tax, insurance, depreciation, interest and maintenance & wear. For a fair comparison of different modes, the full production costs of current public transport services were estimated before direct subsidies.

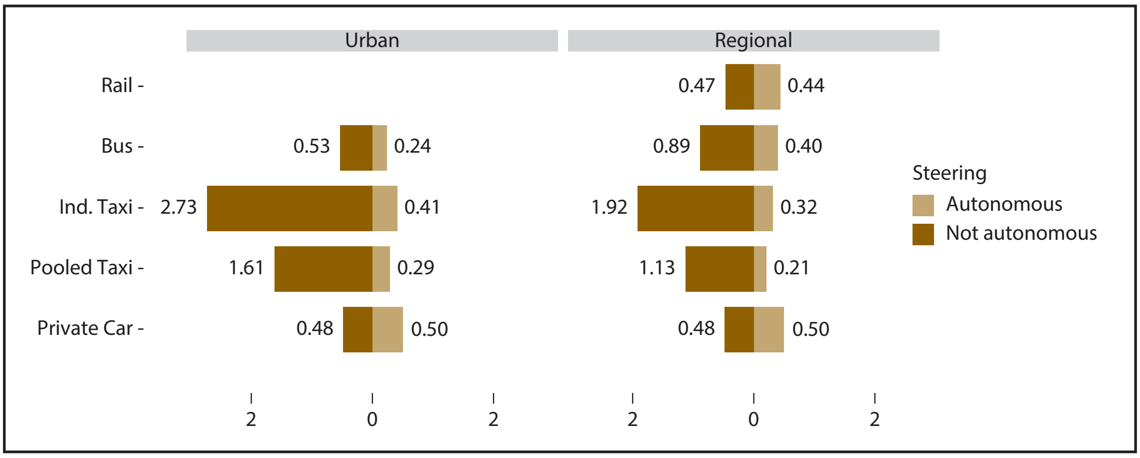

Figure 2.4 – *Cost comparison of different modes with and without autonomous vehicle technology (Bösch et al., 2018)*

2.2.4 Mobility

Developments around CAV can play a role in the offer of mobility solutions. This can be explained by a recent policy change of the Flemish government (*Vlaamse Overheid, Departement Mobiliteit en Openbare Werken*, n.d.). In June 2019, the Flemish government replaced the old decree on basic mobility with the new decree on basic accessibility.

With the **old decree on basic mobility**, public transport companies were obliged to offer every resident of Flanders a stop within a limited distance of his or her place of residence, regardless of whether or not these stops are used. Moreover, the presence of a stop did not guarantee frequent public transport (sometimes it is necessary to use a dial-a-bus) and whether the desired destination is easily accessible from this stop.

With the concept of **basic accessibility**, the Flemish government mainly wants important locations to be more easily accessible for travellers. In doing so, the transport offer should be better adapted to the needs of the passenger. The aim is to concentrate regular public transport mainly around the major axes (possibly even with an increased supply) and to combine it with other modes of transport for the trip to or from the route covered by regular public transport.

The decree on basic accessibility also refers, among other things, to **shared transport for the lowest transport layer** (tailor made transport). It seems that in the long run robotaxis can play a role, especially for the completion of this transport.

2.2.5 Use of space

A private car is not used for a large part of the day. Particularly in an urban context, where demand for space is high, it is possible that **sharing systems with self-driving vehicles reduce the need for parking spaces**[25]. Urban policy pays increasing attention to the promotion of such sharing systems. In addition, there seems to be a tendency to limit the number of parking spaces provided for new housing estates.

On the other hand, certain studies (ITF, 2015) seem to indicate an **increase in the number of kilometres** driven when introducing self-driving vehicles; mainly as a result of repositioning vehicles or picking up or dropping off people or goods. However, with

25 According to a study by OECD/ITF, the number of parking spaces required would fall sharply if all journeys in a city were carried out using shared vehicles (Martinez & Viegas, 2016).

regard to autonomous vehicles, there are considerably more policy options than before to promote meaningful travel. A self-driving vehicle can, after carrying out its transport task, drive away independently to a waiting zone (maximum vehicle storage capacity, minimum disturbance to the community, possibly equipped for maintenance and charging or other secondary functions) or move on its own to the next transport task. However, in order to organise transport efficiently in this way, adapted infrastructure (waiting zones) seems indispensable.

It seems necessary to link **parking policy** and **environmental policy** (Klochikhin, 2019). A large fleet of self-driving vehicles may be required to meet the travel needs during busy hours. During the less busy period, it should be possible to park all these vehicles efficiently while awaiting a next assignment. It should be avoided that self-driving vehicles make long (unnecessary) journeys because parking facilities would be insufficiently available or too expensive (McNulty, 2019).

Future-oriented thinking with regard to parking is already being introduced in some places. For example, project developers in Los Angeles (USA) are asked to design parking garages that can later be converted into homes or shops (Redactie Automobiel Management, 2019a).

In areas that are already congested with cars, autonomous vehicles, without additional measures, will not put an end to **mobility problems**. In urban environments, measures to limit individual transport seem to be crucial for the liveability of this environment (National Association of City Transportation Officials [NACTO], 2019). It cannot be ruled out that cities may consider far-reaching choices in terms of access to (parts of) cities if accessibility and quality of life objectives are not met. The question is to what extent this is necessary. In the first place, people do not a priori choose to aggravate their own journey. In addition, less far-reaching measures can be used, such as dissuasive measures based on the free choice of transport modes. An example suggested by some traffic experts is the pricing of journeys with a differentiation by mode of transport, time and location.

2.2.6 Energy efficiency & environmental friendliness

A motive for the introduction of CAV is energy efficiency and air quality.

A number of applications for (connected) vehicles aim to achieve a **more homogeneous speed**. A more homogenous speed is advantageous on several levels:

- energy consumption and local CO_2 emissions;
- exhaust emissions (mainly PM, PN & NOx) of vehicles with combustion engines;
- non-exhaust emissions of all vehicles (PM & PN of disc brakes, tyres, road surface) due to less (hard) braking.

Examples of applications:

- vehicles that receive information from traffic lights, allowing the vehicle to adapt its speed to the green phase;
- extended green phases for vehicles and controlling of the phases by certain vehicle categories (e.g. priority vehicles);
- anticipative driving behaviour by deploying assistance systems on motorways. This can lead to, for example, fewer stop-and-go traffic (situations in which congestion alternates with free movement).

Emissions are also related to vehicle occupancy. The success of **sharing systems** with autonomous vehicles can have a positive effect on this, especially in an urban context.

Another aspect that plays a role in the traffic loads and on emissions and consumption is the mass of the vehicles. The figure below shows the evolution of the average vehicle mass of new vehicles in Europe, the United States and Japan.

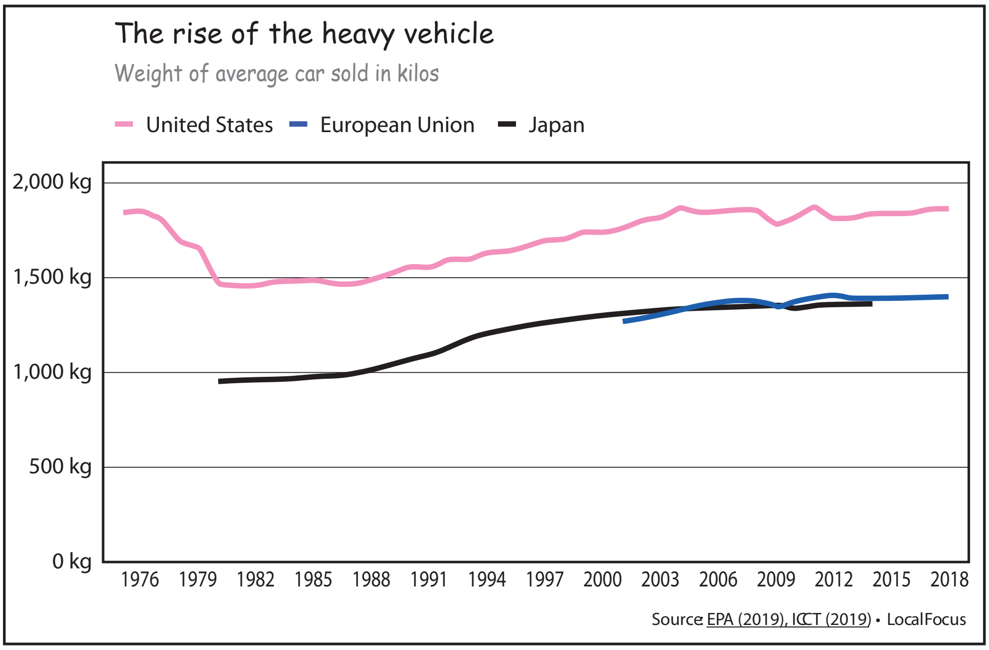

Figure 2.5 – *Evolution of the mass of newly sold cars (Frederik, 2020)*

We will have to wait and see how this develops. The expected greater success of electric vehicles and other technological developments in the coming decades may influence the evolution of average mass. On the one hand a downsizing of vehicles (lighter = less energy consumption) seems possible, on the other hand electric vehicle models with a large driving range require a large battery and are therefore heavier than comparable models with an internal combustion engine.

If self-driving vehicles operate 100 % reliably in the future, they are expected to be involved in fewer or different types of accidents. The homologation requirements for vehicle characteristics that contribute to crashworthiness may then change and are likely to affect the construction and mass of vehicles (Morsink, Klem, Wilmink & de Kievit, 2016) and thus their energy consumption. When vehicle characteristics change this can have an influence on road equipment[26].

As regards infrastructure, there is also the need to provide **charging infrastructure** for battery-electric vehicles and refuelling infrastructure for fuel cell electric vehicles, for which a part of the public space should be reserved.

Policy plans show a tendency to focus on the quality of life in cities, while imposing restrictions on vehicle emissions. If one speaks in terms of vehicle electrification, this is in fact a parallel process, potentially linked to the development of CAV and to the development of sharing systems.

It is often assumed that self-driving vehicles will be powered by electric engines. As the share of these vehicles increases, it is therefore important to provide also sufficient

26 Changing vehicle characteristics also have an impact on the technical specifications of 'forgiving' road equipment. The evaluation methods for these installations take into account average vehicle characteristics (see NBN EN 12767): Passive safety of support structures for road equipment - Requirements and test methods (Bureau for Standardisation [NBN], 2019) and NBN EN 1317: Road restraint systems) (Bureau for Standardisation [NBN], 2002-2010). If these vehicle characteristics change, this should be taken into account in these evaluation methods.

charging facilities for battery electric vehicles and hydrogen refuelling stations for fuel cell electric vehicles (charging infrastructure, charging) (Gowling WLG & UK Automotive, 2018).

2.2.7 Road capacity

The **traffic flow** can be described by means of:

- intensity (q) the number of vehicles per hour;
- density (k) number of vehicles per km of road length;
- speed (u) km/hour.

The **fundamental relation** is the traffic function that describes the relation between intensity and density, speed and density, and speed and intensity ("Fundamentele relatie", 2020).

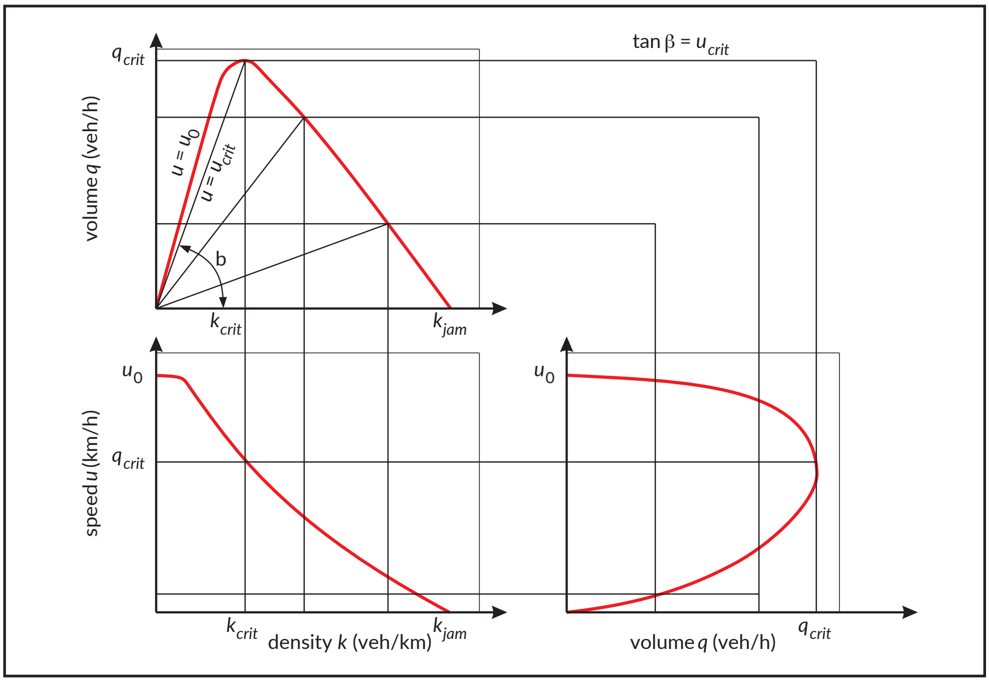

Figure 2.6 – *Relation between intensity, density and speed ("Fundamentele relatie", 2020)*

The behaviour of traffic is determined by several parameters:

- maximum intensity (q_{crit}), also called capacity;
- critical density (k_{crit}), the density at maximum intensity;
- maximum density (k_{jam}) on a road;
- free speed (u_0), the average speed at unhindered flow;
- critical speed (u_{crit}), the speed at which the road is used most efficiently.

Environmental factors influence the parameters (road layout, road surface quality, lane layout, etc.). Capacity is not a fixed figure, but depends on **how traffic is composed** and the weather ("Fundamentele relatie", 2020).

In a scenario with only automated vehicles, the available infrastructure can be used more efficiently, among other things because the **distance between CAV** can be reduced and because of a more homogeneous speed. Simulation results for high volume roads show a variation of 0 to 30 % capacity increase. This depends on several factors: the section, the degree of penetration of autonomous vehicles, the speed, the weather and the proportion of freight traffic (Leeb, 2019).

However, German research shows that in **transition scenarios** for motorways capacity could decrease. Because interactions between self-driving vehicles and vehicles with a human driver are less fluent, a larger safety distance will probably be used, which may indeed reduce capacity in a first phase (Leeb, 2019). The **degree of penetration** of autonomous vehicles in the transition scenario is an important element in this respect. With a sufficient number of autonomous vehicles, reserved lanes for purely autonomous driving can lead to significant capacity gains (Friedrich, 2015). It should be considered how socially acceptable reserved lanes are. If the introduction is too early, perhaps only the 'happy few' can make use of a reserved and easily accessible lane. The silent majority then has to deal with less road capacity.

Reserved lanes for self-driven vehicles can be an incentive to encourage people to switch to other vehicles. If successful, however, it seems likely that such reserved lanes will soon be saturated. Norway's experience with admitting EV (electric vehicles) to bus lanes shows that such admission can also have adverse effects: congestion increases during rush hour in parallel with the sale of EV (Bannon, 2016).

The **theoretical potential for capacity increase** in cities at maximum penetration rates would be around 20 to 40 %. This would apply in particular to traffic light controls: the time needed per vehicle would be reduced, vehicles would be able to accelerate faster and the intersection could be cleared more quickly (Leeb, 2019).

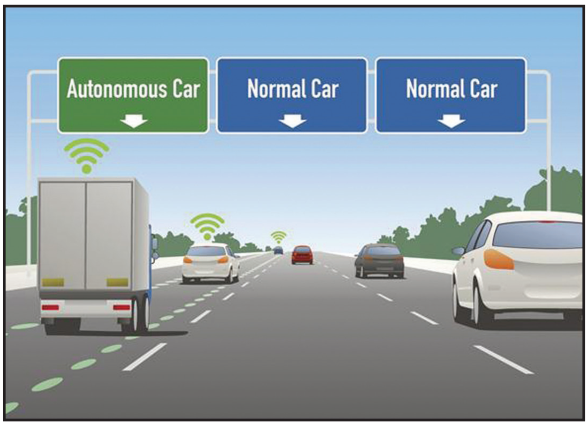

Figure 2.7 – *Reserved lanes for self-driving vehicles (Albricht, 2017)*

2.3 SAE levels

2.3.1 Classification system

The organisation SAE International (a body for standardisation in the automotive industry) has developed a **classification system** for automated vehicles on public roads. The classification system is based on the amount of driver intervention and attention required. In 2018 SAE International updated its classification (called J3016_201806).

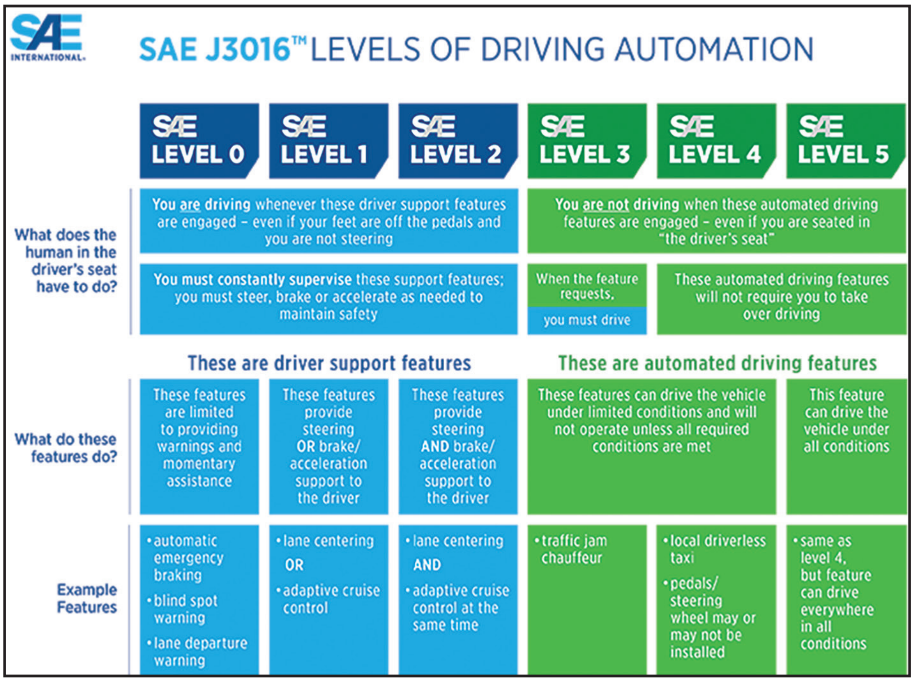

Figure 2.8 – *SAE classification system ('SAE International releases updated visual chart', 2018)*

The system is also used in Belgium (see the code of conduct for testing autonomous vehicles) (Federal Public Service Mobility and Transport, 2016).

Figure 2.9 – *Illustration SAE Level 3 (Metamorworks, n.d.)*

2.3.2 SAE levels and road infrastructure

In the situation without CAV, the transport system is based on interaction between driver, vehicle and road infrastructure[27]. The **human driver** has a direct interaction with the vehicle and with the road infrastructure. As the SAE level increases, less input is required from the driver. Ultimately, at **SAE L5**, the vehicle will be **fully autonomous** and occupants will be able to attend to other matters throughout the journey. A car homologated as SAE L5 is capable of solving any conflict situations completely independently.

27 It concerns the 'road' in the broadest sense: the road structure, the road equipment, and including the nearby road environment. At street level in cities, for example, the road is from facade to facade; on motorways, off-road parts such as verges and central reservations are included.

From SAE Level 3 onwards, automated vehicles are able to handle all or certain driving tasks themselves based on their perception of the driving environment. In the case of SAE Level 0, Level 1 and Level 2, the driver is responsible for monitoring the driving environment. In the case of SAE Levels 1 and 2, the vehicle can already provide limited support to the driver or take over certain driving tasks.

The driver of an automated vehicle up to and including **SAE L3** (conditional automation) must always be able to take over the control of his or her vehicle. Vehicle sensors must be capable of detecting the road, other vehicles and any obstacles in time and, if necessary, inform the driver so that he can take over control of the vehicle promptly. Greater harmonisation and a higher level of quality can contribute to a more reliable functioning of SAE L3 systems, but as there is always a chance that control of the vehicle may have to be taken over by the human driver, infrastructure should also continue to take the human driver into account.

Even at **SAE L4** (high automation), the system still relies on a human driver to deal with critical situations or malfunctions of the technology. Design guidelines still need to consider this[28].

28 Design guidelines: see § 3.2.1 Design guidelines.

For the Dutch *Rijkswaterstaat*, the situation of 100% SAE L5 vehicles is a theoretical exercise (Morsink et al., 2016). They state the following:

- that many modifications to road design may be necessary and meaningful in the longer term in the case of **SAE L5 vehicles** only;
- that not much can be changed in road design as long as there is mixed traffic, with a mix of vehicles of different SAE levels;
- that it is impossible to indicate **the period of time within which** there is a sufficient share of SAE L5 to cause the road design to change (i.e. take the autonomous vehicle with SAE L5 as the starting point and not the manually driven vehicle) as the starting point for the design of (part of) the infrastructure.

It is not preferable to postpone adapting the design guidelines until only SAE L5 vehicles use the road infrastructure. A **continuous evaluation process** is a better approach, but with well-chosen adjustments to the design guidelines:

- the effective adaptation of design guidelines for a particular type or part of road infrastructure is possible if all vehicles have a certain level of capability;
- it is impractical for road authorities and contractors to continually adapt the design guidelines.

In addition, **unavailability of connectivity** must also be taken into account. In this case, vehicle sensors and/or the human driver should take over the driving task and the infrastructure should still allow this to be done in a correct and safe way (Farah, 2016). One may wonder whether users of self-driving vehicles will still be able to suddenly take over the driving task, if automated systems give up or if this is necessary in situations that are more complex.

2.4 CAV roll-out & obstacles

It is not clear how fast the roll-out of autonomous vehicles will go. Vehicles that can be characterised as SAE L3 vehicles have recently been launched on the market. SAE L4 vehicles have been tested[29] for some time. The date of release of SAE L5 vehicles on the market is far from clear: manufacturers' expectations vary widely.

29 For example Google's Waymo project in Arizona (*https://waymo.com/*).

2.4.1 Road infrastructure

Some car manufacturers are insisting on a **higher quality road infrastructure**, while others are mainly relying on the existing road infrastructure when developing autonomous vehicles.

Among other things (the lack of sufficiently visible) road markings is currently an obstacle for some manufacturers for the reliable functioning of autonomous vehicles.

The **reliability of systems** (such as ISA and LDWS) is important for their success and generalisation. There are also a number of infrastructural aspects that play a role, in addition to the technological development and acceptance of the technologies. For example, harmonisation of road infrastructure (colour, reflective materials, etc.) can have a positive influence on the roll-out of CAV.

The **development of camera technology and image processing algorithms** is so rapid that future systems will be able to deal with lower quality markings. Upgrading road markings to support self-driving vehicles may not be necessary. Future developments may allow for the correct recognition by camera systems and processing algorithms of markings that are considered inadequate today. In the future, these road markings may even become completely redundant if accurate geolocation can be relied upon and reliable digital information about the physical infrastructure is available.

As long as there is a mix of vehicles (various SAE levels), it remains extremely important to effectively meet the **quality standards of road markings**. The improvement of the technology (camera, processing) is independent of the necessary maintenance of roads and road markings in particular.

2.4.2 Various obstacles[30]

30 Several initiatives bring together stakeholders with different expertise to set R&D priorities to facilitate the further development of autonomous mobility (e.g. EU CCAM Partnership [*https://ec.europa.eu/transport/themes/its/c-its_en*]) and to identify steps that can be taken by road authorities to support autonomous mobility (e.g. ITF WG preparing transport infrastructure to autonomous mobility).

However, the road to fully autonomous mobility is littered with **obstacles**. The technical aspects (reliable and high-performance communication, accurate and reliable geolocation, etc.) still seem to be relatively 'easily' to solve. For other subjects (ethics, financing, traffic regulations, vehicle homologation, employment, privacy and cybersecurity, etc.), the answer seems a long way off for the time being.

Extreme weather conditions (heavy rainfall, snowflakes are sometimes mistaken for people) and special situations (road works) are also complex for self-driving cars. Systems that function based on the detection of their environment (road markings, traffic signs, etc.) are hampered by this. In the future, detection systems are likely to become more reliable ("Zelfrijdende auto niet langer sneeuwblind", 2020) and perhaps combined with systems that have access to digitised information about the road on which they are travelling (so-called digital infrastructure), making them less dependent on the operation of these sensors. The ITS Framework Directive requires Member States to address road, traffic and transport data used for digital maps.

A complexity not to be underestimated is the **unpredictability of human behaviour**. People do not always follow the traffic rules (e.g. they ignore a red light, or they unexpectedly stop in front of other traffic to double park). It is not to be expected that such behaviour decreases with the roll-out of autonomous vehicles. It is a challenge to learn autonomous vehicles to cope with such unpredictable behaviour. The harmonious and safe combination of automated self-driving vehicles and non-automated and unpredictable pedestrians and cyclists is still an underexposed aspect for the time being (Van Schagen et al., 2017). Recognition of this problem in the first place, and the development of advanced cameras and measuring systems (as a basis for automated vehicle functions) in the second place, offer opportunities to take steps in dealing with unpredictable behaviour.

The **horizon for higher automation levels** is unclear. Optimistic scenarios predict a penetration of 15 % SAE L4 vehicles in 2030 [35]. It is clear that full autonomous mobility (100 % SAE L5 vehicles) is still a long way off: according to some, after 2075 or perhaps never (Morsink et al., 2016).

An article on statements by the eleven largest car manufacturers makes it clear that **Artificial Intelligence** (AI) is inevitable for autonomous cars. However, due to its complexity, it does not seem likely that autonomous vehicles on motorways will be common in the early 2020s (which most car manufacturers declared around 2016) (Faggella, 2020)[31].

31 The article does not specify the description ‘autonomous vehicles on motorways’. The link with SAE levels is unclear.

In SAE L3 vehicles, relatively recently launched on the market, the driver does not drive when the automated driving functions are engaged. However, the driver must drive when requested to do so by the vehicle. This **transition** is critical because automation fails and the driver has to take control of the vehicle in the seconds that follow.

- Insufficient time for the driver to take into account the traffic situation around the vehicle. SAE L4 vehicles do manage that transition in specific use cases (ODD). The end of the use case is known well in advance and this gives the driver the opportunity to prepare and take over the control of the vehicle in time.
- Because the transition may involve critical situations, some car manufacturers are considering switching from **SAE L2 to SAE L4** in one go (Litzler, 2019).

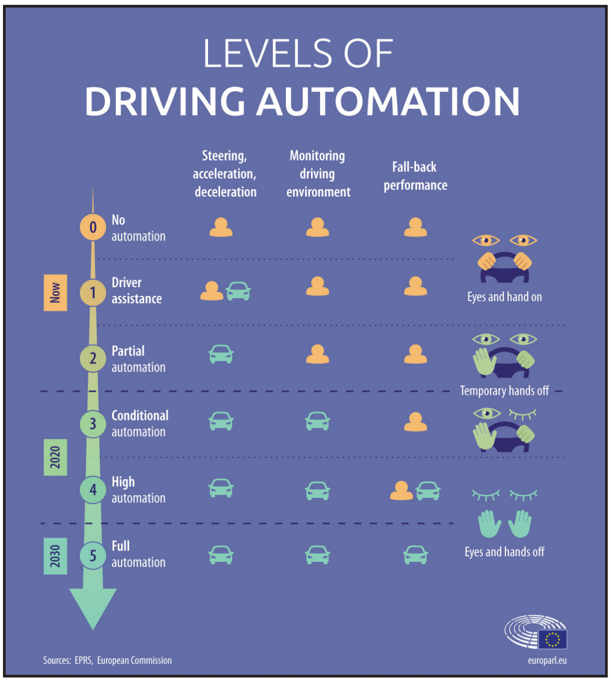

Figure 2.10 – *Degree of automation, EPRS / European Commission (“Self-driving cars in the EU”, 2019)*

The degree of penetration of CAV also depends on the **acceptance of CAV** by all drivers. Is it conceivable that drivers will refrain from autonomous vehicles because they cannot enjoy driving themselves? Should law prescribe the use of autonomous vehicles? If so, under what circumstances? The answer to these questions is still open (Leeb, 2019).

Another important point is people's **expectations** about road safety. Too much confidence in technology can be problematic and put the image of car manufacturers at risk. An accident involving autonomous vehicles undermines public confidence in a key driver of car manufacturers: making the traffic system safer. For car manufacturers, a safe image is extremely important. Car manufacturers are clearly aware of the fact that accidents involving self-driving cars are widely covered in the press. However, the Event Data Recorder (EDR) allows, in the event of an accident, to know the most important accident data as well as who was in control of the vehicle at the time of the incident: the human (driver) or the algorithm.

2.4.3 Foresight

The **future of** road authorities needs to be **explored**, certainly with regard to the roll-out of CAV and the possible implications for society. However, exploring the future is far from easy.

Amara's law (Kerner, 2016) indicates that while we should put the possibilities of technologies into perspective, we should not underestimate them. People are enthusiastic at the beginning of a new technology and overestimate the technological and practical possibilities. As time goes by, people realise that it is more difficult than they guessed and expectations become more attuned to technological developments. In the long term, there is a tendency to underestimate the impact of technological developments.

This **process** is clearly reflected in the development of autonomous vehicles: initially great enthusiasm about the (technical) feasibility and gradually the realisation that it takes quite some time.

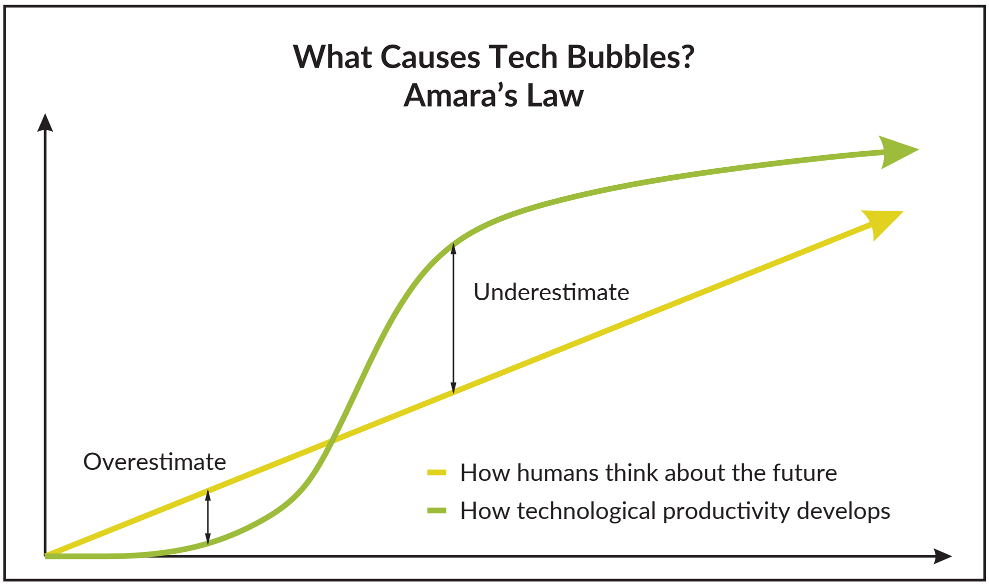

Figure 2.11 – *Amara's law. tech bubble? (Kerner, 2016)*

2.4.4 Cybersecurity

Self-driving cars are advanced computers on wheels; essentially with similar vulnerabilities as other computerized systems. It is extremely important that the **reliability** of these systems can be guaranteed 100 %. Especially if self-driving vehicles are also connected, it is fundamental that the system continues to function even if this connectivity is (briefly) lost. Vehicle functions relevant to safety are best isolated from other systems (ITF, 2018). This fits in with the idea that the operation of emergency systems should not depend on the availability of connectivity[32].

Vehicle access to data means that any external service provider can have direct and uncontrolled access to the data in a motor vehicle. The following figure shows the risks.

[32] For more information about car data: *https://www.cardatafacts.eu/extended-vehicle-concept/*

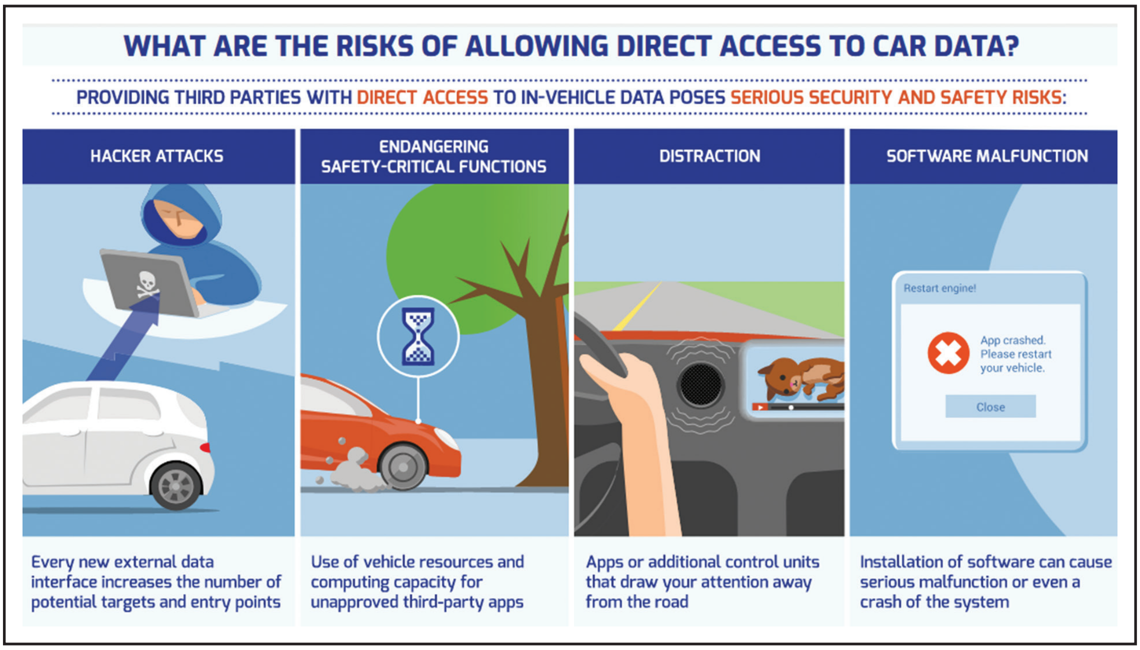

Figure 2.12 – *The risks of direct access to vehicle data ("What are the risks", n.d.)*

Potential dangers include hacker attacks, risk for safety-critical functions, additional safety risks related to driver distraction, and software failuret.

2.5 Autonomous vehicles for limited applications

High development costs for higher levels of automation also play a role in the roll-out. These costs vary according to the type of user. The **development costs** for private autonomous vehicles are difficult to justify for large automotive groups. For example, PSA, one of Europe's largest automotive groups, proposes to continue investing in SAE L4 and SAE L5 for robotaxis and shuttle services, but not in private vehicles with those high levels of automation (Redactie Automobiel Management, 2019c). Moreover, the development of these self-driving shuttles for specific applications on a given trajectory or within a limited area is not only carried out by the traditional automotive groups, but also by relatively new players, sometimes with links to the ICT sector rather than the automotive sector (e.g. Waymo (*https://waymo.com/*), Easymile (*https://easymile.com/*). Several of these new players have meanwhile entered into partnerships with established car manufacturers.

Reserved lanes for autonomous vehicles, on pre-defined sections or within a defined environment, have the advantage that the vehicles have to deal with a more limited amount of peripheral information:

- starts and stops, for example, can be programmed permanently in the vehicle;
- physical beacons can help improve the accuracy of the vehicle's geolocation.

As far as autonomous shuttles are concerned, experience with this type of self-driving vehicle within a defined traffic environment can help developers to improve the algorithms that steer the vehicle's behaviour and gain more knowledge about the interaction between the self-driving vehicle, its surroundings and other road users[33]. Such a simplified environment increases reliability in the initial phase, as the number of variables is lower.

[33] In 2020 and 2021 *De Lijn* will start experiments with self-driving shuttles at the airport sites in Zaventem and Antwerp. STIB/MIVB is continuing its tests, followed by a new test at Brugmann Hospital after the tests in Woluwe Park and at the Solvay Campus. Tests will also take place in Louvain-la-Neuve.

There is a big difference between the conditions of use of autonomous shuttles (which are not homologated and not yet on public roads) and vehicles of vehicle manufacturers (homologated for use on public roads). The results of tests are therefore only transferable to a limited extent.

2.6 Mix of vehicles with different SAE levels

The coming decades will therefore be characterised by a **mix of vehicles of different SAE levels**. Fully Autonomous Vehicles (SAE L5) will in all likelihood initially be introduced in situations with little interaction or under specific, limited circumstances (within a specific Operational Design Domain, ODD) (Redactie Automobiel Management, 2019d). Imagine separate lanes on motorways or on restricted bus lanes. However, this does not detract from the fact that tests are already taking place in more complex situations. Examples of shuttle services:

- in the office district of *La Défense* in Paris, where between summer 2017 and summer 2019 an autonomous shuttle bus drove around in an area full of pedestrians (Klochikhin, 2019; "La navette autonome", 2017);
- in the region of Rotterdam (Capelle aan den IJssel), where a new generation ParkShuttle will run on public roads (Lohmann, n.d.).

Various **scenarios** are possible for the roll-out of autonomous vehicles. In Switzerland, for example, development scenarios in three application areas have been considered. It outlines (without setting clear deadlines) development prospects for three categories of transport (individualised motorised transport, public transport on the public road and train traffic) (Leeb, 2019).

Stage	Individualised motorised traffic	Public transport on the public road	Train traffic
1	Driving assistance SAE L1 / L2 on entire network	Experimental road sections	Isolated application
2	SAE L3 permitted on high speed road	Minibus (SAE L4) in normal operation within agglomeration	Selected experimental sections
3	SAE L4 allowed on high speed road, SAE L3 allowed in urban area	Minibus (SAE L5) in normal operation within agglomeration	Automated trains on parts of the network
4	SAE L4 allowed in urban area, SAE L3 on interurban roads	Minibus (SAE L5) in normal operation within agglomeration and beyond	Automated trains on parts of the network
5	SAE L4 permitted on interurban roads, followed by SAE L5 on the entire network	All vehicles (SAE L5) in normal use within agglomeration and beyond. Adaptive public transport / without a course.	Automated trains on the entire network
6	SAE L5 across the network, government influence	Government influence	

Table 2.3 – *AV development scenarios in three application areas, in Switzerland*

2.7 Regulations[34]

[34] § 5.1 Relevant regulations.

European ITS Directive

With Directive 2010/40/EU (2010), Europe has set a number of targets for Intelligent Transport Systems. Very briefly, this Directive aims at an efficient use of vehicle data (or intelligent transport systems) to enable the safe and smooth use of existing transport infrastructure. Specifically, the Directive sets out **six priority actions** on which initial efforts should be concentrated:

- Multimodal Travel Information Services (MMTIS);
- Real-Time Traffic Information Services (RTTI);
- road safety-related minimum universal traffic information free of charge to users;
- eCall;
- information services for safe and secure parking places for trucks and commercial vehicles;
- reservation services for safe and secure parking places for trucks and commercial vehicles.

For the first five actions, Europe has already published **delegated regulations** setting out general guidelines for the elaboration of each action in the different Member States.

Specifically with regard to infrastructure, the following regulations seem to be particularly relevant:

- **Commission Delegated Regulation (EU) 2015/962 (2015)** ('real-time traffic information services') specifies, inter alia, which data relating to infrastructure must be made available via digital information services;
- **Commission Delegated Regulation (EU) No 886/2013** (2013) ('road safety-related minimum universal traffic information') regulates which information should be recorded. These data can be useful to inform other road users, but can also be a good tool for road administrators to better plan interventions.

Communication protocols

Europe has long attempted to impose a **standard** for communication between vehicles themselves and between vehicles and road infrastructure. Disagreement between stakeholders ultimately led to the non-adoption of this C-ITS Delegated Regulation and to the further development of **several communication protocols** (e.g. ITS-G5 and the yet to be rolled out 5G GSM protocol). Initially, existing communication protocols (3G, 4G, 4.5G) will be used. The provision of ITS services will have to take into account the specific characteristics (limitations) of these protocols and the availability or unavailability of this network at the place where a service is intended to be provided (**coverage**).

Strategy for C-ITS services

In November 2016, the European Commission adopted a Communication setting out the strategy for the further development of so-called C-ITS services towards cooperative, connected and autonomous mobility (European Commission [EC], 2016b).

On the basis of an estimate of the costs and benefits, a list was drawn up of:

- services (**Day 1 services**) that are technologically feasible (or become feasible in the short term) and for which there would be market potential;
- Services (**Day 1.5 services**) that should be technologically feasible but for which it is necessary to make further agreements between the various stakeholders.

Hazardous location notifications	Signage applications
Slow or stationary vehicle(s) & Traffic ahead warning	In-vehicle signage
Road works warning	In-vehicle speed limits
Weather conditions	Signal violation / Intersection Safety
Emergency brake light	Traffic signal priority request by designated vehicles
Emergency vehicle approaching	Green Light Optimal Speed Advisory (GLOSA)
Other hazardous notifications	Probe vehicle data
	Shockwave Damping (falls under ETSI Category "local hazard warning")

Table 2.4 – *Day 1 services for C-ITS services, European Commission*

Information on fueling & charging stations for alternative fuel vehicles
Vulnerable Road user protection
On street parking management & information
Off street parking information
Park & Ride information
Connected & Cooperative navigation into and out of the city (1st and last mile, parking, route advice, coordinated traffic lights)
Traffic information & Smart routing

Table 2.5 – *Day 1.5 services for C-ITS services, European Commission*

Belgian regulations

The European ITS Directive has been **transposed into Belgian law**, and a cooperation agreement has been concluded between the Federal Public Service for Mobility and Transport and the Regions.

The ITS Framework Directive has also been transposed at regional level, and there are a number of additional documents (decisions, draft notes).

In consultation with partners, the FPS Mobility and Transport drew up a **code of conduct** for testing in Belgium. This provides a framework that defines[35] roles and responsibilities.

[35] § 5.3 Testing: test sites & Living Labs (EU).

Chapter 3
CAV and infrastructure

Depending on the location, the **characteristics** of the available traffic vary considerably:

- Motorways are mostly used by fast motorised vehicles and drivers who try to make both short and long journeys on the appropriate infrastructure in a smooth and comfortable way.
- In urban environments, the speed is much lower and we see a mix of pedestrians, cyclists, classic vehicles and more and more new means of transport (micromobility[36]).
- Roads that often have a mix of residential, business and commercial functions are characterised by a mix of vehicles that sometimes travel at very different speeds.

36 § 3.3.3 Emerging micromobility.

The composition of the existing traffic is not static. Government policy can have a major impact on the composition and related characteristics. This is the case in both cities and on motorways. Cities, in particular, seek to improve quality of life through a variety of measures affecting access to the city for and/or the availability of certain categories of means of transport.

The roll-out of autonomous vehicles is strongly linked to the development of **digital infrastructure**, and is likely to have an impact on the **physical infrastructure**. Clarification of both is further included[37] in the text.

37 § 3.1 Physical infrastructure and digital infrastructure.

Depending on the location or type of infrastructure, and on how and by whom this infrastructure is used, the gradual introduction of self-driving vehicles may require adaptations. In order to clarify this distinction, a further distinction is made in the text between **motorways** and **urban environments**[38]. Attention is paid to the short term and the, for the time being utopian, future scenario in which only automated vehicles participate in traffic.

38 § 3.2 Motorways and § 3.3 Roads in an urban environment.

The requirements for road infrastructure are now defined on the basis of human driver's needs. In order to make self-driving traffic possible, attention will probably have to be extended to other aspects (e.g. communication with signage, whether or not a digital representation of the road is available, etc.). In the **Inframix project**[39], so-called **ISAD levels** (Infrastructure Support Levels for Automated Driving) were developed in which an impetus is given to define the minimum infrastructure (physical and digital) required to enable certain self-driving functions. Such an approach makes sense to clarify what level of automation is possible on a given road section.

39 *www.inframix.eu*. See also § 4.2.2 Research for testing.

Various organisations, both in Belgium and abroad, organise tests with so-called **shuttles** (relatively slow self-driving vans for a defined route). Based on the experiences of these organisations, a final section formulates a number of points for attention in relation to road infrastructure[40].

40 § 3.4 Shuttles.

Certain considerations are relevant in several situations. As a result, there may be repetitions in the text.

3.1 Physical infrastructure and digital infrastructure

It is expected that the functioning of fully automated vehicles will be partially based on **detailed (digital) maps** and **accurate GNSS localisation**[41]. In addition to the road design/layout (lanes, entrances, exits, etc.), these maps will also contain detailed information on the traffic rules in force (speeds, availability of road sections, etc.) and the presence of road equipment (restraint systems, etc.).

[41] The accuracy of Galileo (*https://gssc.esa.int/navipedia/index.php/Galileo_Performances*) does not currently seem sufficient for positioning self-driving vehicles. Accurate positioning may require the use of additional techniques.

If the road configuration changes (e.g. as a result of road works), it is important that this **changed configuration** is updated in real time on these digital maps and is immediately available to the vehicles relying on this map information when performing their driving task ("Adapting infrastructure", 2016; Transport Systems Catapult, 2017).

On the other hand, digital infrastructure can also play a role as a **back-up** for some physical infrastructure (in particular road signage). If road signs or markings are insufficiently recognisable or if variable message signs are defective, digital infrastructure and communication can still ensure that the correct message reaches the vehicle.

In **road construction and maintenance** it will therefore probably be extremely important that the correct situation is entered into this digital model, so that it is always a correct representation of the actual physical infrastructure.

Commission Delegated Regulation (EU) 2015/962 (2015) encourages stakeholders to provide and keep up to date so-called 'static road data' and 'dynamic road data' via digital maps. Tools such as **Building Information Modelling** (BIM), a digital model of an existing and/or planned construction consisting of objects with linked information, can undoubtedly make an important contribution to this. In any case, it would seem that contractors will have an important additional task to keep this digital model up to date. It is possible that specialised companies will emerge to assist contractors, as is the case when drawing up signage plans, communication plans and nuisance abatement plans.

Road authorities are likely to play a role in making digital information available on their physical infrastructure. Automobile manufacturers and manufacturers of ADAS systems use this information to enable certain vehicle functions. It is important that good – European or international – agreements are made about the format of all these data.

In addition, this information must be made available in the vehicle in a reliable and fast manner. A **standardised communication protocol** and the necessary **hardware** (data cabling and communication infrastructure) for it to function will become an important part of the infrastructure needed for self-driving vehicles to function optimally.

3.2 Motorways

Motorways are the connection between countries, regions, large cities and between important (air)ports. They are mostly used by motorised vehicles for smooth and comfortable transport over short and long distances.

Motorways seem a priori to be the environment where autonomous vehicles can operate with the fewest problems. The traffic situation is simpler, speeds are uniform, and neither crossing traffic or traffic in the opposite direction nor cyclists or pedestrians, need to be taken into account. Implementation on motorways is the **least complex** (Vermaat et al., 2017). Nevertheless, it should be kept in mind that the majority of vehicles on motorways have no or only limited self-driving functions for some time yet.

3.2.1 Design guidelines

For the design of road infrastructure, designers can benefit from design guidelines, in which crucial knowledge and expertise are shared. In this part, we pay attention to a number of important elements of the design guidelines.

At the basis of these design guidelines are a number of **concepts**, such as the self-explaining road and the forgiving road. They form the philosophy of the design guidelines and serve to reduce the likelihood and consequences of errors made by human drivers.

In the **transition scenario**, human drivers and the mistakes they may make should still be taken into account in any case. The concepts of 'forgiving road' and 'self-explaining road' remain fully valid as long as **human intervention** is **required**: they provide an important handhold for limiting errors and reducing their consequences.

In a **fully autonomous scenario**, however, there are no longer human drivers. If the reliability of the systems can be guaranteed, the road design of a motorway does not need to take into account these human drivers to the same extent as in the above scenario. On the other hand, it is not inconceivable that automated systems also fail. It remains to be examined whether infrastructure can play a role in solving such problem situations (e.g. lay-by zone for individual vehicle malfunctions, other adaptations to handle larger problem situations safely, etc.).

Geometric road design (horizontal + vertical)

The landscape and existing buildings also determine the geometry of a road. In the current situation with human drivers, long and straight road sections are avoided (limitation of the horizontal straight position) in order to retain the road user's attention. This gives the road a curvy geometry. This will continue to be important as long as the share of autonomous vehicles of high SAE levels does not predominate[42].

[42] § 2.4 Roll-out CAV & obstacles.

In order to carry out a driving task safely, it is important that a driver has a good view of the road ahead, that any obstacles can be detected in time and that there is sufficient time to slow down or stop safely if necessary. The recommendations for the **geometry** of a road are largely based on the need of a human driver to maintain a good **overview** of the road and other traffic. For self-driving vehicles functioning only with vehicle sensors, this requirement will continue to apply and the current guidelines for infrastructure used by human drivers can be maintained.

When designing curves, design guidelines assume minimal skid resistance and crossfall and a certain design speed. In addition, a certain margin is taken into account for drivers who do not respect the recommended speeds. The recommendations for the geometry of vertical curves are then mainly determined by wishes for an overview of the road ahead (crest curves) or for a comfortable road course (sag curves).

Connected vehicles, on the other hand, can obtain the information on the route (possibly limited to certain ODD) via digital systems (detailed navigation information, V2X communication). In those cases, the need for a good visual overview of the road and the road environment may become less compelling. On the other hand, the road geometry has to be adapted to the comfort requirements of road users.

As the proportion of self-driving vehicles increases, so-called **target group lanes** can be introduced for vehicles of a higher SAE level. These lanes for autonomous driving could be narrower. However, it should be avoided that human drivers use the lanes for automated vehicles or imitate the behaviour of self-driving vehicles. This could lead to too high speeds (in curves) or too short intermediate distances (Morsink et al., 2016).

(Large) **speed differences** are problematic for road safety. Interactions between vehicles at different speeds remain difficult. When building infrastructure, road safety benefits from a uniform speed. Self-driving vehicles make it easier to reduce speed differences between individual vehicles.

For example, in a scenario with 100 % SAE L5 vehicles, the limitation of the horizontal straight sections to hold the attention of a human driver would no longer be necessary (Morsink et al., 2016). The question remains to what extent the effort to adapt the road outweighs the costs.

Provided accurate positioning, (connected) **SAE L5 vehicles** can better maintain their track and (due to the on-board map information) better anticipate a changing alignment of the road. As a result, the **speed** in a curve may be slightly higher or the **curve radius** may be reduced. For this to happen, however, the skid resistance and crossfall of the road must be sufficient to allow these higher speeds. On the other hand, the comfort of the occupants of self-driving vehicles and the possible impact on energy consumption should also be taken into account when reducing the radius of the curve or increasing the speed.

If motorways were to be used exclusively by fully self-driving vehicles, it would seem that the road geometry recommendations could evolve (Paulsen, 2018). For the time being, however, this is a totally **utopian scenario**. As long as there are non-automated vehicles circulating on motorways, human drivers should remain the starting point for the design recommendations. Self-driving vehicles should therefore take into account the infrastructure as it is designed and built today. Only when all vehicles are self-driving, and provided that they can deal with a modified road geometry, effective adjustments to this geometry can be considered. The possibilities of new vehicles evolve rapidly. It makes sense to **periodically examine design recommendations** against these new possibilities and to investigate whether sensible future-proof adjustments are possible.

Width and occupation of lanes

Provided that the positioning is sufficiently accurate and reliable, a narrower lane may be sufficient for a CAV (Morsink et al., 2016; Paulsen, 2018). By narrowing lanes of existing roads and slightly reducing the width of emergency stopping lanes and central reservation, it is even possible in some cases to create an additional lane (Farah, 2016; Paulsen, 2018). However, for vehicles with a human driver, the current lane width **recommendations** should be **maintained**. In addition, lanes should be sufficiently wide to allow the passage of intervention vehicles.

In case of a narrower lane, there is less deviation on the lateral position of a CAV. Together with a possibly higher occupancy of vehicles and the increase in mass, this means that the road structure is put under higher **loads**. Experiences with self-driving shuttles, although not on motorways, sometimes show increased wear of the road surface in the track of the vehicle after relatively short periods. In this sense, road structures that are less sensitive to wear seem a better choice for self-driving vehicles.

The **perception of safety of the occupants** (margin of fear) of a self-driving vehicle (Farah, 2016; Morsink et al., 2016) must also be taken into account if they would drive closer together through narrow lanes.

Belgium specifically allows **motorcyclists** (under certain conditions) to overtake slower moving traffic between lanes. If lanes became narrower, this would become impossible.

At busy times the maximum capacity of motorways is reached or even exceeded. It is assumed that the **capacity of lanes** used **exclusively** by self-driving vehicles – due to the smaller distances between them – can increase by up to 30 %. Even without increasing the speed, as a transitional measure to a scenario of 100 % self-driving vehicles, the capacity of the available network can thus be increased (Vermaat et al., 2017; Wilmink, Calvert, de Kievit, Landen & Zlocki, 2017).

However, experience with reserved lanes for electric vehicles in Norway showed that these lanes became[43] saturated very quickly. In general, increased capacity may lead to increased demand for the use of autonomous vehicles to the detriment of other modes of transport. It is unclear how this would affect the modal split.

43 It should be noted that Norway has implemented several measures to rapidly electrify its vehicle fleet.

In a scenario where vehicles with different degrees of automation share the same road section, adjustment of the occupation is not an issue. Moreover, in practice it appears that the distance between self-driving vehicles and non-self-driving vehicles (mixed traffic) is higher than the distance between vehicles with only human drivers (human drivers look further than just the next vehicle). As more people start to rely on vehicle technology, it therefore seems that with unchanged infrastructure (or unaltered use of the existing infrastructure) the fluency of traffic will first decrease even further.

In order to facilitate rush hour traffic, it is already possible to set up (new) highways with a tidal flow system. This is a dynamic lane layout with one or more lanes with a variable driving direction. The announcement of a changed layout can be made by means of Variable Message Signs (VMS), possibly supplemented with movable lane dividers.

In a **futuristic scenario**, physically separated **lanes may become superfluous** and the available road width can be divided into lanes in a flexible and dynamic way as a function of the time of day, weather conditions and the actual traffic (so-called target group lanes), possibly even with different speed regimes. Lane allocation can be done via I2V communication. If self-driving trucks are excluded from one or more lanes via automation, lanes on road sections with no or very limited interaction may be narrowed. In places where there is a lot of exchange (entrances and exits) narrowing may not be appropriate.

The capacity of lanes used exclusively by self-driving vehicles could be increased by up to 30 % by reducing the distance between vehicles. Together with the increasing weight of vehicles, this means a higher load on the road structure. When (re)constructing bridges and civil engineering structures, it can therefore make sense to consider higher loads.

However, it is **difficult to estimate** when this will become **meaningful**. No doubt it will take decades before the entire vehicle fleet will be self-driving and the width of lanes and occupation of the road can be effectively adapted. Infrastructure being built today will probably have to be replaced before there is a fully self-driving vehicle fleet.

Merging and exit lanes / auxiliary lanes

The **dimensioning** of merging and exit lanes, auxiliary lanes and similar parallel structures (*Ministerie van de Vlaamse Gemeenschap [MVG], Agentschap Wegen en Verkeer [AWV], Afdeling Expertise Verkeer en Telematica, Team Veiligheid en Ontwerp*, 2018) should allow vehicles to enter or exit without excessive speed differences with through traffic, and allow the capacity of the road to be used optimally (in the case of auxiliary lanes).

In mixed traffic, the interaction between automated and non-automated vehicles is likely to be somewhat less fluent. It is therefore possible that such exchange points will have to be slightly larger in size to allow fluent traffic (Morsink et al., 2016). The (re)construction of infrastructure can respond to this by already **providing space** to facilitate future extension.

On the other hand, it is noticeable that at the moment quite a few drivers do not always use long auxiliary lanes as intended (auxiliary lanes are meant to exit soon or to merge only at the end of the auxiliary lane). Drivers are often tempted to leave the traffic jam via the auxiliary lane in order to catch up with the traffic jam and re-join at the end. The meaning of the signalling of an auxiliary lane does not seem sufficiently clear or the correct use of this road section is insufficiently known.

Longer parallel structures (or the possibility of extending them) seem meaningful for mixed traffic. It can be assumed that self-driving vehicles – if correctly programmed – will make proper use of this extra space. However, human drivers should be encouraged to make proper use of this extra space.

In the case of completely self-driving traffic, merging and exiting can be automated via communication between the vehicles involved (Morsink et al., 2016). It is important to **provide sufficient space** for this. For some exits, an increase in capacity may make sense. Even if this is not necessary according to the current recommendations, it does seem interesting to provide sufficient space to extend the capacity of parallel structures at a later date, should this prove necessary for the secure exchange of automated traffic.

Emergency stopping lane / lay-bys / intervention lanes

Motorways are standard provided with an emergency stopping lane. **Emergency stopping lanes** allow you to stop safely in the event of a breakdown and reduce inconvenience to other traffic, but are not a safe place to stay.

On certain road sections, the emergency stopping lane can be transformed into a rush-hour lane at certain times. In such cases, lay-bys should be provided at regular intervals. The *Vademecum Weginfrastructuur* (Flanders) recommends making emergency lanes sufficiently wide to allow alternative use at a later stage (*MVG, AWV, Afdeling Expertise Verkeer en Telematica, Team Veiligheid en Ontwerp*, 2018).

An automated vehicle may decide to stop on the emergency stopping lane or at a lay-by if, for example, the occupant becomes unwell or is unable to take control of the vehicle if requested to do so. However, on an emergency stopping lane, this can lead to dangerous situations if the occupants are unable to leave the vehicle. In this sense, **lay-bys** appear to be a better solution than a continuous emergency stopping lane. The location of these emergency stopping lanes must be known for these self-driving vehicles. As more self-driving vehicles or vehicles with Driver Fatigue Monitor

(DFM) join traffic, there is a risk that the use of these lay-bys will increase and that consideration will have to be given to adapting the number and dimensions of these facilities (Transport Systems Catapult, 2017).

On the other hand, a sufficient number of lay-bys remains necessary for interventions (maintenance and incident management).

Cross section

The **classic cross section** of a motorway is two pavements, each with a number of lanes, separated by a central reserve and on the outer sides by an emergency stopping lane with or without a paved shoulder. On the central reserve, the two directions of travel are separated by a restraint system. If there are dangerous obstacles on the shoulder, they are also shielded by a metal or concrete restraint system.

For **mixed traffic** this remains the **preferred solution**. In some cases (no obstacles such as lighting columns or bridge pillars in the central reserve), a single sided restraint system in the central reserve seems to offer advantages over a double-sided system. Providing slightly more space between the edge of the lane and the restraint system gives the driver a better chance of correcting anomalous behaviour and slightly reduces the risk of collision with the restraint system.

If motorways are used **exclusively** by self-driving vehicles (SAE L5), an adaptation of the cross section can be considered. For example, the width of the safety zone, an important part of the forgiving road concept, could be reduced (Farah, 2016; Morsink et al., 2016).

If in a distant future all vehicles are self-driving, Lane Keeping Systems will guarantee that these vehicles remain within their lane. In such cases, lanes, shoulders, safety zones and the central reserve could be made **narrower** or even become **superfluous**. This could lead to additional lanes becoming available within the existing pavement (Farah, 2016; Transport Systems Catapult, 2017).

However, road construction recommendations will have to continue to take account of **human drivers** and the **mistakes** they make for some time to come. In a future where automation is increasingly taking over the tasks of a human driver or correcting his errors, the road environment may have to be adapted depending on the reliability with which self-driving vehicles operate (ITF, 2018).

Truck platoons

The transport sector has been promoting truck platooning for several years. By allowing trucks to travel in a convoy, emissions can be reduced and goods transported more efficiently in comparison with traditional trucks. In a truck convoy the **leading truck** has a human driver. If the following vehicles are (partly) automated, they communicate with the leading vehicle and automatically respond to the signals sent by the leading vehicle. The speed with which these automatic systems react is higher than that of a human driver (Paulsen, 2018).

A truck platoon of two or three vehicles takes up a lot more space than an individual truck. A truck platoon also causes higher loads on the road structure and on bridges. In addition, **pilot projects** have shown that the length of such truck platoons causes difficulties while merging, exiting and overtaking. If a truck platoon changes lanes or has to take a turn, other road users may experience this as an inconvenience due to the temporary limitation of the overview of other traffic. It is irrelevant whether the convoy consists (in part) of automated vehicles (Paulsen, 2018).

Truck platooning is only possible on **selected routes**, due, among other things, to the extra space taken up compared to an individual vehicle. Some countries are considering setting up certain infrastructure for exclusive use by lorry traffic and truck platoons (Ohern, 2016).

By automating truck platoons as well, the required space can be reduced slightly, so that more routes become eligible for truck platooning.

The higher reaction speed attributed to automated vehicles also applies to self-driving truck platoons. If other safety margins (speed) are also optimised, the space taken up by truck platoons on the road can be somewhat reduced. For existing roads, automation of truck platoons can broaden the application slightly. When constructing new roads that are only accessible to self-driving vehicles (including truck platoons), the geometry requirements can be relaxed and the road can better match the course of the terrain (Paulsen, 2018).

3.2.2 Influence of AV on road construction

Occupation / road structure

When all vehicles are self-driving, the **capacity** of the existing infrastructure can probably be increased by having vehicles driving closer to each other and reducing the width of lanes. Just by reducing the distance between vehicles, a capacity gain of up to 30 % would be possible.

The increasing demand for mobility and the resulting expected increase in traffic will be partly due to individual transport and partly to collective transport and freight traffic.

The influence of vehicle electrification on mass seems to go in two directions. On the one hand, electric vehicles with a large range require extra battery capacity, which makes these vehicles generally heavier than comparable models with an internal combustion engine. On the other hand, electric cars with a limited range are also being developed (e.g. only for city traffic or commuting over a limited distance). For the limited range, a battery with lower power (and weight) is sufficient. Such vehicles can therefore be made lighter.

In practice, it appears that the **weight of vehicles** is mainly increasing[44] at the moment.

[44] § 2.2.6 Energy efficiency & environmental friendliness.

All these evolutions suggest that roads **will be under heavier loads** in the future. Moreover, the larger number of vehicles (cars and trucks) will only increase the consequences of the unavailability of a road (section). Sustainable roads (in the sense of sufficient lifespan) and high availability are therefore even more important (Paulsen, 2018).

In the **transitional situation**, however, it seems likely that the capacity of a road will decrease slightly so as not to cause unsafe situations. The high reaction speed of autonomous vehicles requires, for non-autonomous vehicles, a greater distance between them in order to be able to stop in time if necessary. In this sense, it does not immediately seem necessary to change road structures drastically. However, the roads being built today should also be able to serve if, in the not too distant future, lanes are reserved for self-driving vehicles that for example drive with shorter distances between them (high occupancy toll lanes (Farah, 2016)). Initiatives that increase the **sustainability of roads** and/or techniques that allow **fast repairs** therefore already seem useful for non-automated traffic. As the proportion of autonomous vehicles increases, this becomes even more relevant.

When **constructing or renovating bridges**, it is also best to investigate whether the structure is capable of safely supporting any higher traffic loads in the future.

Road surface quality

The quality of the road surface remains an important point of attention.

Connected vehicles can be an interesting source of data for road authorities to get a more accurate picture of the state of the road surface and to plan repairs[45] and maintenance more efficiently.

[45] § 2.1.1 Connected, autonomous and § 3.3.7 Digital infrastructure and services

It should be avoided that small irregularities in the road surface lead to **erroneous detection** by self-driving vehicles or driver assistance systems (e.g. erroneous detection of a longitudinal joint as a marking) resulting in unexpected behaviour. It seems likely that the characteristics of self-driving vehicles will lead to different road surface quality requirements (Morsink et al., 2016).

Independently of developments in the field of autonomous transport, it remains necessary to use road surfaces that meet **minimum requirements**. A balance will always have to be found between driving comfort, safety, fuel consumption, rolling noise, etc. It makes sense to pay extra attention to these surface characteristics during execution and maintenance and to use techniques that pursue a sustainable road surface quality. For the time being, it seems more important that the current requirements for surface characteristics are effectively achieved (and that a road continues to meet them) than to tighten these current requirements.

Sensors in the road structure

In addition to intelligent vehicles and digital infrastructure, **sensors** can also provide useful information for road authorities and contribute to better and safer road use. Sensors can store and transmit information on the volume of traffic, on invisible obstacles on or along the road or even serve as an alternative guidance system for vehicles (Clapaud, 2017) or to increase[46] the **accuracy and reliability of positioning** based on GNSS systems (GPS, Galileo, etc.). However, it is then crucial that these sensors have an autonomy comparable to the lifetime of the road structure in which they are integrated (Clapaud, 2017).

[46] Alternative techniques for the positioning of self-driving vehicles. See Voronov, Hultén, Wedlin & Englund (2016).

3.2.3 Road equipment

Visibility and harmonisation of road markings and road signs

Road markings and road signs are today the **standard way** of informing road users where they can drive and what driving behaviour is expected of them. However, there are already vehicles on the market that are equipped with **technology** to recognise the messages these markings and road signs give and either pass them on to the driver or control the vehicle's behaviour (e.g. LKA).

A (permanent) and highly visible **road marking** in all weather conditions is therefore important both for human drivers and for the proper functioning of the current generation of driving task assistance systems. In addition to sufficient visibility, however, it is also important that existing markings are uniform and have the same meaning.

Specifically for detection systems, a sufficient **contrast** between the marking and the road surface is important for the recognition of the marking (Somers, 2019d). The importance of highly visible markings for detection systems is subject to evolution. New cameras and image processing techniques make less and less demands on the markings.

For **road signs**, good visibility and harmonisation are equally important. Moreover, the differences between different countries and regions are best limited. In the case of road signs, additional information is already provided by means of text (so-called under-signs). For the current generation of vehicle sensors, it is not self-evident to correctly recognise and interpret all the different possibilities. This will probably be much easier if there is a digital representation of the physical infrastructure and applicable traffic rules or if there is communication between road signs and vehicles.

The visibility and recognisability of signs must be sufficient to support certain functions in self-driving vehicles. On the other hand, however, **detection systems in connected self-driving vehicles** can also potentially register and communicate at which locations this visibility and recognisability are insufficient. In this way it is possible to detect more efficiently where maintenance is most needed. Both self-driving vehicles and human drivers will benefit from such a win-win situation. A precondition for such a system is, of course, to reach agreements on the exchange of data.

In the long term, when all vehicles are fully automated and all the information that vehicles need for their driving task is available via digital infrastructure, the **importance of road signs** for automated road users may decrease. All the information currently given to human drivers via road signs (speed limits, priority rules, etc.) can then be stored in databases and made available to self-driving vehicles via digital systems. In this way, the traffic rules in force along a particular section of road can become much **more dynamic** (for example, in the event of road works, accidents or adverse weather conditions). Along roads that are also used by non-automated road users (cyclists, pedestrians), signage is probably still the best way to inform these users about their expected behaviour.

Restraint systems

Restraint systems must be able to **protect** the **environment** from unintentional intrusion by vehicles getting off the road. At the same time, the consequences of such collisions for the **occupants** of the oncoming vehicle should be limited. Both aspects will be evaluated according to existing European test methods.

Vehicles seem to be getting anything but lighter. Electric vehicles are heavier than the same model with internal combustion engine. Even if more efforts are made in the future on collective transport, it seems that the mass of vehicles will not decrease. New developments related to road restraint systems should consider this trend.

Especially as long as there are human drivers, restraint systems remain an important means of limiting the consequences of accidents, both for the occupants of the vehicle and for the environment. If self-driving vehicles function correctly, so-called **single accidents** should become a thing of the past. In such cases, restraint systems may become superfluous or may be reserved for high-risk locations or along roads that have not yet been adapted for automated driving. In those cases, however, these installations have to **evolve** with the vehicle fleet. On the other hand, restraint systems – as an alternative to road markings – can also be used for traffic guidance (Morsink et al., 2016).

Variable Message Signs (VMS)

Variable Message Signs are increasingly used to pass on messages to drivers and to direct traffic. For the time being, these messages are interpreted mainly by human drivers. As more vehicles are equipped with sensors, it becomes important that, in addition to the classic static signs, these **sensors** are also able to recognise the messages of these variable message signs.

The current generation of cameras appears to be less able to handle so-called scanned LED arrays (Vantomme, 2019). Pulsed LED arrays or **VMS** that can be equipped with communication technology therefore offer more security for the future.

As with road signs and markings, the **role of variable message signs** is likely to decline in the long term. Information that a vehicle needs to perform its driving task can then be transmitted via digital systems.

3.3 Roads in an urban environment

In an urban environment, the challenge for autonomous vehicles is of a different and often **more complex nature than on motorways**.

The situation in a relatively homogeneous environment, such as a **motorway** with only interaction between vehicles is a special type of environment. The maximum allowed speed is high, but the speed differences between vehicles remain limited. Most of the crossings are grade-separated and there are several lanes next to each other. It is in this environment that the guidelines for infrastructure design can evolve as a function of the proportion of autonomous vehicles with a high SAE level.

In an **urban environment**, we have to deal with non-homogeneous roads and a very diverse use.

3.3.1 Challenge in urban context

On the positive side for autonomous vehicles, we can note **speed** and **construction**.

- Urban speed limits are lower, making the stopping distance shorter.
- An autonomous vehicle, compared to a vehicle with a driver, has the advantage that the shape and structure of the buildings alongside the road play a limited role in performing the driving task. A driver undergoes continuous visual impressions and is also distracted by roadside objects or events that are not relevant to the driving task. The attention of autonomous vehicles is only focused on the execution of the driving task. In addition, a self-driving vehicle can take into account events or situations that are not yet visible, on the basis of communicated data. Based on that information, an autonomous vehicle can make traffic-safe decisions, for example by adjusting its trajectory or adjusting its speed.

The greater complexity of the situation in the urban context in relation to motorways has to do with the **non-homogeneous nature of the roads** (in relation to motorways) and their use.

- People use the roads for a **variety of journeys** with **all kinds of vehicles**: on foot, bicycle, moped, car, motorbike, truck and, for some time now, various types of micromobility. In an urban environment, a significant proportion of road users are not yet connected to the transport network. Self-driving vehicles should primarily be able to detect these users correctly themselves.
- There is a large number and **variety of objects** that may or may not be part of the road (sign posts, lighting posts, speed cameras, fences, bicycle sheds, utility poles, advertising panels, street furniture, speed inhibitors, etc.). A **correct digital representation** of the location and the relevant physical characteristics can be important for making choices by the self-driving vehicle. For example, in the case of installations along roads where higher speeds are permitted, it may be interesting to have information about the passive safety of crashworthiness of the installation. AV may then use this information to assess the risk of collision.
- A **distinction** should be made between vehicles that should be able to drive anywhere (the automated car) and vehicles that drive on a predetermined route (shuttles). The shuttles are distinguished by the fact that the routes are coded[47] on a map.

[47] § 3.4 Shuttles.

Figure 3.1 – *Different modes of transport (Gabriel12, n.d.)*

3.3.2 Roles and interests

Stakeholders all have interests, which need to be **reconciled** to ensure that autonomous vehicles can make a positive contribution to the challenges cities are facing (inclusiveness, environmental aspects, safety, accessibility, liveability, etc.).

It remains important for **car manufacturers** to be profitable. In addition to the traditional sale of vehicles, a range of services is increasingly being added, such as offering a mobility package and maintaining a fleet of vehicles. Vehicles must meet safety and environmental requirements (emissions, noise).

Public transport companies offer alternative modes of transport to meet the demand for travel. The vehicles used (buses, trams or metros) and future vehicles (shuttles and robotaxi-like transport) must be safe, clean and accessible.

The interest of **public space managers**, cities and municipalities, lies in defending the interests of citizens in terms of reachability, quality of life, accessibility and road safety.

Some experts expect the ill-considered introduction of self-driving vehicles in an urban environment to have a rather negative effect on the **liveability** of a city. They believe that an ill-considered introduction of self-driving vehicles will increase traffic (e.g. by shifting from public transport to automated transport services, driving around of 'empty' vehicles - zombie cars, increased mileage through increased shared transport, etc.) (Smolnicki, 2017)[48]. It is therefore important to see the introduction of self-driving cars as an **opportunity** to rethink urban mobility.

48 See also, in relation to latent demand for transport, § 2.2.3 Congestion.

Autonomous mobility seems to be a knife that cuts both ways. On the one hand, transport is highly likely to become safer and more accessible. On the other hand, the introduction of autonomous mobility without an appropriate framework may also have a number of side effects (shift from public transport to individual transport services, mobility problems, etc.) (Smolnicki, 2017).

The various interests play a role in the way in which autonomous vehicles will find their way into society. In cities in particular, the development of autonomous vehicles is only one of the developments in mobility that needs to be given due consideration. **Other developments**, together with technologies for autonomous mobility, are leading to major changes in urban mobility. Some important changes are, in random order:

- the emerging micromobility;
- the sharing systems;
- the greening of transport;
- the adjustment of speed limits;
- the digital infrastructure;
- commitment to slow mobility and accessibility;
- diversification of public transport services;
- delivery of goods.

3.3.3 Emerging micromobility

Besides the traditional bicycle, moped and walking, there are many forms of transportation on the market or under development. These means of transport, such as scooters and mono wheels, are called 'micromobility'. An important aspect that plays a role is the **place** of micromobility **on the road**. It involves questions such as 'where may they be used', 'where may they be parked', and 'how are they charged'. The government has to make regulatory choices in this respect. Specifically:

- Allow micromobility on footpaths, cycle paths, bus lanes? (Transportation for America [T4America], 2018).
- Permitting parking everywhere, delineating zones or providing new types of parking spaces?
- In the case of an electric vehicle sharing system (e-steps and the like), which recharging options to choose?
- Will the new means of transport be connected and recognized (interesting for management reasons but also for AV development and security)?

The different forms of parking each have advantages and disadvantages (T4America, 2018). Cities are increasingly opting for **parking restrictions**. The Brussels Capital Region, for example, first proceeded to define zones where it is forbidden to leave shared scooters and then tested specific parking spaces for shared scooters ("Specifieke parkeerplaatsen", 2019).

The increasing use of micromobility increases the number of types of road users that an AV must be able to **detect**. Micromobility users are about the same size as a pedestrian or cyclist, but usually move more quickly. Autonomous vehicles should in any case be able to correctly analyse and assess the behaviour of micromobility users. Many of the new means of transport can be connected. However, not all forms of micromobility are detectable yet. Further developments are required before AV can detect all forms of micromobility under all circumstances and estimate their behaviour. A self-driving vehicle of level SAE L3 can transfer responsibility to the driver in case of unpredictability. For the SAE L4 and L5 levels, this transfer is no longer intended.

As far as **road infrastructure** is concerned, micromobility has other interests besides the place of use (journey, parking, charging). The **road surface** must be of sufficient quality, and the number of obstacles they encounter must be limited. This contributes to the predictability of the behaviour of micromobile road users, which is important for autonomous vehicles.

The **speed** of scooters and monowheels is a major challenge for pedestrians, cyclists, wheelchair users, etc. It may also make sense to consider some kind of ISA for these means of transport depending on their use in certain environments (pedestrian zone, zone 30, bicycle lanes, shared use of space, etc.).

3.3.4 Sharing systems

In cities there is a **theoretical potential** for vehicle sharing. Simulations show that shared cars could replace several private cars, which would lead to less space consumption. The estimated number of cars replaced by a shared car ranges from 2.5 to 13, but the studies have limitations that lead to an overestimation (e.g. they focus on early adopters) (Liao, Molin, Timmermans & van Wee, 2020).

Sharing systems also have the potential to positively influence the **modal split** and contribute to a more environmentally friendly transport behaviour. After all, users of shared cars are more frequently multimodal users (public transport, cycling, walking, micromobility) than individual car owners. On the other hand, numerous population groups (young people, the elderly, people with disabilities, people without a driving licence, etc.) cannot or are not allowed to use SAE L0 to L3 vehicles independently, which they could do with SAE L4 and L5 autonomous vehicles. This can contribute to a more **inclusive society**.

However, there is also a downside: if AV is introduced without also focusing on alternatives to individual transport, it risks adversely affecting the modal split. This could lead to the (further) **congestion of the cities**.

For sustainable urban mobility, the future of autonomous vehicles undoubtedly goes **hand in hand** with a modal split policy. Several **options** are available for such a policy: sharing systems, MaaS, public transport, environmental zones, road pricing, restrictions on access to certain zones in cities, etc.

MaaS and sharing systems that also employ **self-driving vehicles** (robotaxis) seem to have great potential. According to the so-called Oslo study (COWI & PTV Group, 2019):

- 7 % of the current vehicle fleet would be sufficient if all users of private transport switched to (self-driving) vehicles with shared journeys (**ride sharing**);
- under the same condition, the number of vehicle kilometres driven would also be reduced by 14 %;
- if only the vehicle and not the journey were shared (**ride hailing**), 9 % of the vehicle fleet would suffice but the number of vehicle kilometres travelled would increase by 26 %;
- if public transport users were also to use only ride sharing services, 16 % of the current vehicle fleet would suffice and all trams and buses could disappear. Abolition of public transport obviously leads to a sharp increase in vehicle kilometres travelled.

A study for Lisbon (ITF, 2015) gives similar results. Both studies also set quality of service requirements; the maximum waiting time (time between vehicle call and effective availability) and the maximum delay (e.g. to pick up other users) are limited to acceptable levels.

	BASE	1A	1B	2A	2B	3A	3B	3
						FROM BUS AND TRAM TO TAXIBUS		
	PRIVATE CARS 2020	FROM PRIVATE CAR TO CAR SHARING	FROM PRIVATE CAR TO SHARED TAXI	FROM PRIVATE CAR, BUS AND TRAM TO CAR SHARING	FROM PRIVATE CAR, BUS AND TRAM TO SHARED TAXI	FROM PRIVATE CAR TO CAR SHARING	FROM PRIVATE CAR TO SHARED TAXI	FROM TRAM AND BUS TO TAXIBUS
VEHICLE KILOMETERS – IN SERVICE (MILLION)	4.4	4.0	3.1	6.1	4.6	5.5	4.7	1.5
VEHICLE KILOMETERS – EMPTY VEHICLE (MILLION)	0	1.5	0.6	2.4	1.1	1.7	0.9	0.2
VEHICLE KM (MILLION)	4.4	5.5	3.7	8.6	5.7	7.3	5.5	1.8
VEHICLE KILOMETERS SHARE – IN SERVICE	100%	73%	83%	72%	81%	76%	84%	86%
VEHICLE KILOMETERS SHARE – EMPTY VEHICLE	0%	27%	17%	28%	19%	24%	16%	14%

Table 3.1 – *KPI for fleet size and vehicle kilometres in MaaS system, Oslo study, PTV Group, April 2019 (COWI & PTV Group, 2019)*

[49] PUDO: zones for picking up and dropping off passengers (COWI & PTV Group, 2019).

In terms of **road infrastructure**, the sharing systems require enjoyable and safe parking, drop-off and pick-up zones (so-called PUDOs[49]). Such mobility hubs can only be successful if users or providers of sharing systems feel safe there and can leave their vehicles behind without fear of being vandalised. In the second half of 2019, for example, it was decided to remove JUMP bikes from some municipalities in Brussels due to vandalism (Brussels-Capital Region, 2019).

Shared vehicles of **floating sharing services** are allowed to park in regulated parking spaces where private cars are also allowed to park. In the case of **station based car sharing**, allocated parking spaces must be provided (see further under 'greening of vehicles').

Sharing systems (cars, bicycles) have a greater chance of success if they are easily **accessible** (at a short distance from departure or easily accessible by public transport). Governments have a role to play here, negotiating with providers of organised subsystems before rolling out the service in the specific area. In order to easily connect sharing systems to other sharing systems or other modes of transport, investments need to be made in adapted infrastructure. A regulatory challenge is to deal with the growing popularity of **private car sharing** (a group of individuals/households systematically using a jointly owned car).

Redevelopment of roads with less space for vehicles and more space for alternatives (public transport, bicycle, walking and micromobility) can be an option depending on the modal split, accessibility and liveability. The degree of penetration of autonomous vehicles, whether as a subsystem or not, has an influence on this. For a city that faces this challenge and wants to understand the effects, it seems crucial to develop a vision of the future and **scenarios** and to make model-based extrapolations.

3.3.5 Greening of transport

The **environmental requirements** for vehicles are becoming increasingly stringent. Cities have the option of setting up a LEZ (low emission zone).

Some cities (Paris, Brussels, etc.) have already spoken out in favour of **banning vehicles with combustion engines**.

For instance, the **Brussels** government recently approved the regional climate plan, with a commitment to strengthen access criteria and to introduce a ban on diesel vehicles in 2030 and on petrol and LPG vehicles in 2035. In addition, an extension of the scope of application (integration of motorcycles in the LEZ) has been opted for, and the creation of 'zero-emission zones' (ZEZ) is considered in the Brussels Pentagon or in certain areas, e.g. in trading hubs. This ZEZ would have stricter access criteria compared to the LEZ (Redactie e-Drivers, 2019).

In **Rotterdam**, positive and preventive measures are being taken. The objective of the LEZ was achieved in just a few years. The city is switching to new measures, such as agreements with companies in the city centre to supply only with electric vehicles, more space for vulnerable road users, public transport, shared transport and cleaner modes of transport ("Waarom Rotterdam", 2019).

For some organisations, the LEZ does not go far enough. They advocate a ZEZ (**zero-emission zone**) (Transport & Environment (TE), 2019).

For other organisations, the LEZ goes just too far, and there are doubts about the effectiveness of an LEZ (BV, 2020). In **Stuttgart**, during the COVID-19 lockdown (spring 2020), it was decided to abolish the particulate matter alarm on the basis of new insights into the relationship between air measurements and the use of older diesel vehicles. This was done based on data collected in the particularly low traffic period since the lockdown.

In order to achieve environmental objectives, it is useful to **encourage** the use of clean vehicles. For the widespread use and purchase of clean vehicles running on electricity or hydrogen, several steps remain to be taken. Among other things, the purchase price should be lowered and there should be more clarity about the performance of these vehicles (e.g. the uncertainty about the range of electric vehicles). At the same time, the **charging and filling infrastructure** (electricity, hydrogen, CNG, etc.) still needs to undergo major development. It is important for users to be able to easily supply their vehicles with the energy source[50] that is indispensable for the time being. Potentially interested parties should not be deterred by the threat of changing conditions of use[51]. Cities and governments can choose to **coordinate policies** on sharing systems, autonomous vehicles and clean vehicles.

As far as the physical **infrastructure** is concerned, some types of clean vehicles obviously require charging and filling infrastructure, but parking is also an issue. **Parking** remains necessary, also for AV. After all, in a 24-hour economy, there are major fluctuations in transport demand. It makes little sense, for example at night, to have a large proportion of vehicles driving around without a purpose. It is also true that for efficient operation by autonomous vehicles during peak hours, a large fleet is required. **Driving without a purpose** (zombie cars) contributes unnecessarily to congestion and energy consumption (whether at off-peak or peak times). With regard to parking, there is still no clear answer to some **essential questions**:

- Where in the city (or outside) should AV parking spaces be provided?
- From what charging level does an electrically autonomous sharing car need to charge, or still drive around for a trip that is still feasible?
- How does the cost of parking compare to the cost of driving?

As far as the charging of individual electric vehicles is concerned, it may be **private charging** and **public charging**. Charging options for private individuals must be carefully selected. Cables that are put from the electric car to a facade over a footway are particularly problematic for pedestrians and persons with reduced mobility (PRM)[52]. With **inductive charging** (also called wireless charging), an electric car can be charged without the intervention of cables or a charging point. In practice, it is parked above a base plate. It is important that the distance between the cabling under the surface and the element that captures the electricity is limited. For longer distances, the transfer of energy decreases rapidly.

An induction plate has the advantage of taking less space compared to charging stations. Other **advantages**: less sensitive to vandalism, and ease of use. However, there are also **drawbacks** to induction charging: the higher investment cost due to the more complex installation, the lack of standards and the loss of power (Brussels Mobility, 2019). The efficiency of inductive charging is limited to approx. 90 %, compared to 99 % when charging via plug-in systems (O'Brian, 2019).

An **alternative charging system** is the pantograph system. This can be used to charge faster at a stop or in a parking lot (such as for electric buses).

50 There are four CNG charging stations in the Brussels-Capital Region (situation on 10/06/2020 according to *https://www.gas.be/nl/rijden-op-cng/station-zoeker*).

51 Ionity (a European charging network of rapid chargers) decided to increase the prices for charging via their rapid chargers from 2020.

52 Persons with physical or mental disabilities are considered to be PRM, but also, for example, elderly persons or pregnant women who have difficulty moving around, persons with a leg in a plaster cast, etc. (Federal Public Service Mobility and Transport, n.d.).

Management of public charging stations is a challenge: there is the phenomenon of cars **parked longer than necessary** for charging. Matching the supply to the demand for public charging stations and traditional parking spaces also requires a great deal of attention. A system must be worked out that is fair for both autonomous vehicles and 'traditional' vehicles (Carter, 2019).

Finally, electric vehicles can **accelerate** and **decelerate** faster than vehicles with thermal engines. As far as electric (autonomous) vehicles are concerned, the question is how the software will take speed and comfort into account. Unnecessary decelerations will have to be avoided. The tyres of electric vehicles are more subject to wear due to faster acceleration and deceleration, but it is unclear whether this driving behaviour affects the forces acting on a road structure.

In addition to using less polluting vehicles, cities can of course also reduce the environmental impact of transport by promoting **collective transport** and **slow mobility**.

3.3.6 Adjustment of speed limits

There is a trend towards **lower speed limits** in cities, prompted by traffic safety and environmental considerations (in terms of noise). The number of streets with a speed limit of 30 km/h is increasing, and speed limits higher than 50 km/h are under pressure. For example, the Brussels-Capital Region (BCR) included in the draft Good Move mobility plan the action to introduce the speed limit of 30 km/h as the standard speed over the entire territory, with higher speed limits rather as an exception for roads with mainly a traffic function. In the public survey, the demand for low-traffic neighbourhoods with a speed limit of 30 km/h was approved by almost three-quarters of the 8 500 citizens who took the effort to complete the online survey (Brussels Mobility, 2019)[53].

[53] Quiet neighbourhoods, where fewer cars drive at a speed adapted to local life (30 km/h): totally agree 54 %, rather agree 20 %, rather not agree with 12 %, not agree at all 14 %) (Brussels Mobility, 2019).

The graph on the left shows the relationship between speed, acceleration and fuel consumption. The graph on the right relates the speed to rolling and engine noise. At lower speeds we see higher fuel consumption, and lower total vehicle noise. In areas where the residential function takes precedence, local authorities give priority to traffic safety and quality of life (including traffic noise). Both benefit from lower speeds.

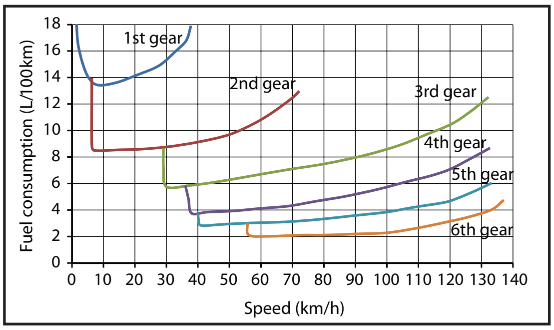

Figure 3.2 – *Relationship between speed, acceleration and fuel consumption (Nasir, Noor, Kalam & Masum, 2014)*

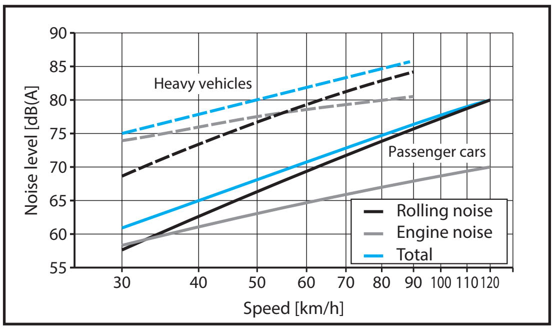

Figure 3.3 – *Relationship between speed and vehicle noise (rolling sound and engine noise) (Amundsen & Klæboe, 2005)*

Policy plans speak out in favour of residential areas where **liveability** takes **precedence** over traffic flow. The choice of liveable residential areas and lower speed limits can reduce the speed differences between vehicles. That is interesting for autonomous vehicles. They have to deal with a multitude of information from moving pedestrians and vehicles. At lower driving speeds, they have a little more margin for reaction. Testing with autonomous vehicles on urban public roads is safer if there are low speed limits and the speed differences are effectively small.

In Europe, from 2022 all new vehicles must be equipped with advanced safety measures. These are ISA (**intelligent speed assistance**), alcohol interlock installation facilitation, driver drowsiness and attention warning, advanced driver distraction warning, emergency stop signal, reversing detection and event data recorder ("European Parliament", 2019). As far as ISA is concerned, it is unclear at this stage whether this will be an open system (only indication to the driver of the maximum authorised speed), a closed system (driving speed is actively limited to the maximum authorised speed) or something in between.

With the traffic safety concept 'self-explaining road' in mind, the **road infrastructure** is best adapted to these lower speed limits. These can be **small – or larger – interventions** with regard to the road profile, such as effectively narrowing the carriageway or working with elements outside the carriageway providing visual narrowing. **Speed ramps** are also an option. This type of intervention can enforce greater respect for speed limits. Such adaptations remain **necessary** in a mixed scenario with vehicles of different SAE levels and with ISA systems that do not effectively enforce speed. For some of the vehicles, the drivers still have the power to decide on the speed driven in that situation. As soon as systems in (autonomous) vehicles can enforce speeds effectively, physical speed reducing measures or changes to the road profile are no longer necessary for that purpose. It is **expected** that it will still take years before all vehicles are equipped with effective speed enforcement systems.

Adapted road profiles for the benefit of vulnerable road users are not only useful for driven speeds, but also for (urban) policies aimed at a more sustainable modal split in favour of pedestrians, cyclists, micromobility and public transport.

3.3.7 Digital infrastructure and services

Further digitisation is taking place in all parts of society. Themes such as Smart City, Mobility as a Service (**MaaS**) are high on the policy agenda of cities that want to take a big step forward towards a modern and sustainable society.

There is a strong focus in the field of mobility on ITS services that make road use safer and more fluent. Examples include green time negotiation (Intelligent Traffic Controllers for public transport, emergency services and certain categories of road users or information on specific situations (road works, accidents, etc.).

The debate on the technique to be applied (**5G or ITS-G5**) has not yet been settled. However, it is clear that the primary purpose of these services is to bring information into connected vehicles. As long as drivers are in control, it is up to the driver to do something with the information. The risk of drivers reacting differently will continue to exist. For vehicles of automation levels SAE L4 and L5, the vehicles themselves react. Information about relevant characteristics of the road or objects can be important for choosing their optimal behaviour and path. For a homogeneous behaviour, **agreements** will have to be made with:

- car manufacturers (what behaviour should certain information give rise to);
- digital map makers (what information is recorded on these maps);
- authorities (which behaviour is desirable).

Safety Related Traffic Information (Commission Delegated Regulation (EU) No 886/2013 (2013) (**SRTI**) focuses on **traffic management** in situations that endanger road safety (e.g. black ice, mobile road works, traffic accidents). For example, digital infrastructure will make it possible to inform road users about the course of a road, applicable traffic rules, recommended driving behaviour in function of external factors (other vehicles, weather conditions, etc.). This is also important in an urban context. **Central incident management** is one of the possibilities. Successful experiments with SRTI may lead to the sharing of other data (e.g. data relevant for mobility or road maintenance) between the vehicle sector and road authorities, in addition to data relevant for safety.

However, a lot remains **unclear**, such as:

- The speed of development of Global Navigation Satellite System (GNSS) and positioning and information products (map infrastructure). It is very important for autonomous vehicles that the system cannot fail. Satellites may also fail, so GNSS receivers need to be able to pick up signals from other systems. GNSS differ in terms of accuracy. For example, the European **Galileo** is more accurate than the American **GPS** (Global Positioning System) (T4America, 2018).
- The speed of development of the **sensors on the AV**. The question here is if the autonomous vehicles themselves become smarter and smarter, will there be less need for a digital representation of the physical infrastructure?
- The development of **private ownership** of passenger cars and the **admission** of vehicle types in cities. With the developments in the field of MaaS and the theoretically very flexible service that robotaxis as a public service can supply at a lower financial cost, what is the future for the number of private vehicles sold? What choices does the policy make? Will **policy choices** continue to be based primarily on what is technologically possible? Will company cars be replaced by a mobility service? Are private vehicles still allowed in certain areas in the future? Despite the development of mobility plans with a strong focus on digitisation, the **elaboration of the policy** is not easy to predict.

As regards **road infrastructure**, it is above all the **accessories** of the road that need to be adapted: traffic controls, information panels (parking reference) and road signs will have to be able to communicate with connected and autonomous vehicles in addition to displaying the message. The classic road signs are in principle also detectable and interpretable by cameras and algorithms. However, these road signs are often supplemented with all kinds of information about when or to whom the sign applies. For the time being, current technology does not seem to be able to recognise this **additional information** correctly. A digital representation of the traffic sign, including the additions on validity, is probably a good option to address this issue.

The self-driving vehicles that are being experimented with today on limited sections function mainly on the basis of GNSS navigation and sensors. For large-scale developments, **detailed and up-to-date maps** seem to be an important prerequisite. Road authorities and contractors may have an important role to play (in relation to up-to-date information on road works). It is necessary to make arrangements with the **service providers** (a single service provider or a coordinated group of service providers). There is still a major challenge to improve the accuracy of existing systems and websites (GIPOD, Osiris, Trafiroute, etc.) so that they are in line with reality and autonomous vehicles can be optimally informed.

As far as **intersections** are concerned, an evolution is possible in the (very) long term towards intersections where the interaction is purely based on communication. If all vehicles are of automation level SAE L5 and everyone moving is connected, traffic lights at intersections could no longer be needed. However, **traffic lights** will continue to play an important role for a long time to come.

With **new installations or replacements**, it is already sensible to use intelligent traffic lights controllers (iTLC). These systems enable communication between the traffic light and the road user. This can be done in both directions: based on individual road user data from an additional information source and detection loops, an iTLC can better adapt the controls to the actual traffic situation. **iTLC** is suitable for:

- **prioritising**, for example, providing a longer green phase for a particular direction or combination of directions, or an additional green phase for certain categories of vehicles;
- **informing**, providing in-car information from the iTLC. For example, it concerns the recommended speed, time to red (TTR) or time to green (TTG), with which the road user can adjust his driving behaviour (speed, attention level);
- **optimising** the handling at one or more intersections by making data from vehicles available to traffic controllers (Hormann & Bakker, 2019).

3.3.8 Slow mobility and accessibility

In future visions for cities, individual motorised transport is generally allocated less space than it does today. Pedestrians, cyclists and different types of micromobility can use the space thus freed up. The space can also be greened or receive a useful or pleasant purpose. Very likely there will be an additional need for hubs where traffic participants can switch between different means of transport. A point of attention in future visions remains the need for space for autonomous vehicles (e.g. waiting space, entry and exit locations).

Low speeds, fewer passenger vehicles and more non-motorised road users are likely to lead to more **interactions** between slow-moving vehicles and other road users. Narrower roads with fewer and slower vehicles allow pedestrians to cross more easily and not necessarily walk up to a crossing. To allow this in a comfortable way (e.g. for persons with reduced mobility), **level differences** between pedestrian zones and the roadway can be limited (as already recommended for accessibility). Different colours and different types of pavement (NACTO, 2019) can distinguish zones intended for different users. At low speeds (30 km/h or lower) you can ask to what extent there is still a need for specific pedestrian crossings.

It is important, when designing roads in an appropriate way, also to ensure sufficient **accessibility for emergency services** and other service providers who need to have easy access to the place where their services are required.

Self-driving vehicles will have to take these developments into account. In cities, for example, continuous traffic flows of closely spaced CAV should be avoided in order to allow fluent crossing of pedestrians and cyclists. Specific areas (for waiting, boarding and alighting) for autonomous vehicles must be safely implanted. Particularly in the case of hubs, it is important to match that space to the needs of all modes in the environment.

3.3.9 Diversification of public transport services

Transport companies play an important role in urban mobility. **Traditional transport** (buses, trams, metro) remains the backbone of their services. These vehicles have little (bus) or no (tram, metro) flexibility as far as routes are concerned. They also have, because of their dimensions, limitations with regard to how they can be fitted into the urban environment. In order to meet a growing demand for public transport, public transport companies are trying to **diversify** their services.

[54] See § 3.4 Shuttles.

The **self-driving (electric) shuttle**[54] is one such example. A major advantage of a self-driving shuttle is that the high personnel costs can be eliminated, if legislation allows offering a service on public roads without a driver or attendant. Extensive **testing** of such shuttles in different environments should answer the questions of whether this new concept meets the needs of both users and (local) authorities, under which conditions they work correctly and whether there is a profitable business case.

With the current generation of shuttles, a **fixed trajectory** is programmed with indication of points of interest (where the speed is e.g. slightly reduced), in combination with vehicle sensors to detect local situations.

As the tests progress, the so-called Operational Design Domain (ODD), the environment in which testing takes place, can become more complex. Regulatory and administrative aspects are looked at, but certainly also the infrastructural and environmental aspects are considered. As far as **infrastructure** is concerned, several aspects are important:

- the quality of the road surface is important to avoid false detections;
- it is crucial that a route contains as few (visual) obstacles as possible that could interfere with a correct interpretation of the road by the vehicle;
- in cities, cellular coverage may be much better than outside cities, but experience shows that a number of reference points need to be placed along a route if GNSS coverage is too limited due to, for example, vegetation;
- the vehicles need charging infrastructure and parking space when not in use. The parking lot should be protected (protection against vandalism).

3.3.10 Delivery of goods

In addition to transporting people, self-driving vehicles can of course also be used for the distribution of goods. The **last mile** in the distribution of goods is time consuming and costly. Especially in cities, it is often not easy to use trucks for the distribution of goods. There are all kinds of scenarios for using self-driving vehicles to organise this more efficiently. These include self-driving delivery points, fully self-driving small robots that depart from a distribution centre or from a larger autonomous vehicle (mother ship) or autonomous vehicles to support a human courier (so that he can focus on his main task), etc.[55]

[55] See VIL project ALEES (self-driving logistical electric units for urban environments) with a number of possible scenarios for the deployment of self-driving vehicles within urban logistics (Claeys, 2018).

All these large and small means of transport make use of the existing infrastructure. Automation may possibly allow such means of transport to use reserved lanes (e.g. bus lanes). It is important that the use of the means of freight transport does not cause any additional inconvenience to the services for which these lanes have been reserved.

Distribution centres may have an important role to play. On the one hand, these should be easily accessible for the supply of goods, if possible multimodal. On the other hand, the location is important: it must allow deliveries to be made as efficiently as possible.

3.4 Shuttles

Shuttles were mentioned several times in the challenges in the urban context. In this chapter we specifically discuss the **scope**, **testing** and **development** of shuttles. We make the link back to the challenges of mobility. Next, we look at the link with the **physical road infrastructure**.

3.4.1 Scope

It is common for the concept of shuttle to be linked to **services**, to establish shuttle services. Shuttle services refer to the type of services that are primarily aimed at carrying passengers on a fixed route between two fixed points, with possibly more than one boarding and drop-off point between them. The services are usually for short or medium distances lasting less than an hour.

Autonomous shuttles are a **new type** of collective transport. They are small vehicles that can move autonomously. They are electrically driven and are rather limited in size. Because of their size they are very suitable to transport a limited number of passengers without taking up a lot of public space. For public transport companies and other providers of mobility services it is a major advantage in the longer term that autonomous shuttles can actually be used **without a driver or attendant**. This is achievable if tests have shown that shuttles are fully capable of doing so, if regulations permit it, and if there is a favourable business case.

Autonomous shuttles offer a substantially different service than the so-called **robotaxis**. Robotaxis are also self-driving taxis without a driver (automation level SAE L4 or L5), which are, however, intended for an on-demand mobility service for use on public roads. Autonomous shuttles are currently SAE L4 vehicles that can travel pre-defined routes on or off the public highway. Robotaxis, on the other hand, have a flexible trajectory. If shuttles can also be used on flexible routes, the difference between this type of service and robotaxis is likely to disappear over time.

Shuttles are intended for multiple (groups of) users. With robotaxis, there is another distinction between vehicles that are used by one user (or a group of users belonging together) and where no other users are picked up during the ride (ride hailing). In a variant, it is possible that other users are picked up during the ride and that they deviate from the originally planned route (ride sharing)[56].

56 § 3.3 Roads in an urban environment.

Autonomous shuttles and robotaxis have at least one aspect in common: the idea that no driver or attendant is needed to drive the vehicles. From a **business** point of view, this is a very interesting development for transport providers.

The developments of autonomous shuttles and robotaxis are parallel processes. Some experts say that robotaxis could be **widely introduced** in cities within 10 years and later also in more rural areas. The big advantage of these robotaxis is that they can take care of door-to-door trips (or slightly less extensive trips, from 'street corner' to 'street corner' where passengers with different destinations might be more inclined to use one shared vehicle). In the city of Phoenix, Waymo (*https://waymo.com/*) is already starting with robotaxis without a 'reserve man' to take over driving tasks. In China, the operating costs of a fleet of robotaxis are expected to fall below the level of a conventional vehicle fleet by the end of 2030 (Pizzuto, Thomas, Wang & Wu, 2019). A lower cost can then allow to focus on a better service and shorter waiting times for users.

A great success of robotaxis can have **consequences** for other means of transportation. First, the number of private vehicles could be reduced. Public transport services may also suffer, both the traditional forms and the new forms such as the autonomous shuttle.

Robotaxis, however, only add value if they are also shared efficiently. If robotaxis are used as individual personal transport, the number of kilometres driven will increase dramatically (partly due to the empty kilometres to pick up passengers) and the congestion problem will only get worse.

Simulations for Lisbon showed that replacing the vehicle fleet with 10 % (off-peak period) to 35 % (peak period) **shared** robotaxis, combined with high-performance public transport, could be sufficient to meet current transport demand (Martinez & Viegas, 2016), without reducing the quality of the service[57] provided with a comparable availability to that of a private means of transport. According to the same study, **parking** on the street could disappear almost completely, freeing up a lot of space that could be used differently. According to other studies, there are still a lot of **open questions** about the alleged disappearance of the need for parking[58].

57 In the simulation, the maximum waiting times are limited as a function of the total distance to be covered (max. 10 minutes for a distance greater than 12 km). The total time lost (due to congestions or diversions) is also limited as a function of that total distance (max. 15 minutes for distances greater than 12 km).

58 § 3.3.5 Greening of transport.

3.4.2 Testing

The development path of shuttles runs via **comprehensive tests** on predetermined routes. The testing of autonomous shuttles takes place in different environments. This may involve tests outside or on public roads, with varying degrees of presence of other road users (pedestrians, cyclists, or also passenger cars).

Above all, the tests should answer the questions whether the shuttles are meeting the **needs** of users and road authorities, and under which **conditions** the shuttles are working correctly. Before moving to the large-scale roll-out of autonomous shuttles, it is necessary to obtain a good picture of the advantages and disadvantages of such vehicles and the added value to shape new mobility services. The requirements and preconditions in terms of services, environment and road infrastructure, regulations and frameworks must be clear.

For an **overview** of testing in Europe, see International Association of Public Transport (UITP) (n.d.).

During the tests, **safety** and **perception** are the main conditions. As is the case for the automotive groups in the development of autonomous vehicles, it is essential for transport companies to be able to use their vehicles safely on the road. After all, if there is any doubt about safety, people will not use this new service.

Other road users should also accept these self-driving shuttles (Feys, Rombaut, Macharis & Vanhaverbeke, 2020; Rombaut, Feys, Vanobberghen, De Cauwer & Vanhaverbeke, 2020). After all, an autonomous shuttle has no driver who can communicate by eye contact or hand gestures. For other road users this can lead to suspicion and doubt ('did that car notice me?') and to less confidence in autonomous vehicles. Research is being carried out into technologies that can provide an alternative form of communication. When testing, self-driving shuttles are programmed extremely carefully so that the vehicle will always make the safest decision if there is the slightest doubt.

Figure 3.4 – *Self-driving shuttle test (VIAS Institute, 2018)*

When organising tests, it is important to always involve all possible **stakeholders**: the police, local and regional authorities, the Federal Public Service for Mobility and Transport (in connection with the authorisation of vehicles on public roads), public transport companies (in connection with possible interaction with their services), users, local residents and local merchants. It is also essential to communicate clearly about the possibilities, limitations and objectives of the system tested.

Finally, as early as 2015/2016, the FPS Mobility and Transport, in consultation with partners, drew up a **code of conduct** for testing in Belgium[59].

[59] § 5.3 Testing: test sites & Living Labs (EU).

3.4.3 Developments

In § 3.3 Roads in an urban environment, we addressed a series of development directions that have been set in motion in the urban context and on which policy documents speak out. Some of them cannot be seen in isolation from the development of autonomous shuttles.

The autonomous shuttles are a service of collective transport. They are electric and are part of the package of environmentally friendly means of transport that contribute to local liveability. The driving **speed of** autonomous shuttles is, according to several tests, very low. This fits well with the conditions in which the tests are initially carried out: shopping areas and campuses (with many slow pedestrians, cyclists and micromobility), airports (little interaction on the shuttle routes), etc. But outside as well (on public roads, in locations with mixed traffic, including vehicles of the lowest SAE levels), it is safer to run tests with low speed shuttles in situations with limited speed differences. The low speed of self-driving shuttles allows the public space to be shared safely with other, less protected, road users.

The **digital services** that are under development (such as Mobility as a Service, MaaS) should ideally consider the additional offer of autonomous shuttles. These services must provide the necessary flexibility so that testing with autonomous shuttles is an integral part of the MaaS.

With the current generation of shuttles, a **fixed trajectory** is programmed with indication of points of attention (where the speed is e.g. slightly reduced), in combination with vehicle sensors to detect local situations. **High-quality map material** is required for the defined routes. In the logical case that the shuttles are from one transport provider, the question of the provider of this map material (single service or multiple) is irrelevant. Of course, the map must be kept up to date so that the shuttle can take into account the actual situation on site.

3.4.4 Infrastructure

The current tests provide an initial insight into the requirements for road infrastructure and the use of road infrastructure:

- The **quality** of the road surface is important to avoid road surface defects stopping the shuttle or forcing it to take unnecessary evasive manoeuvres. Small defects are no problem. However, with today's technology, larger defects are best avoided.
- **Pollution** of the road surface (mud, dust) can adversely affect the functioning of detection systems and should be avoided.
- (**Visual**) **obstacles** that cause the shuttle to stop unnecessarily should be avoided. Points of attention are vegetation, poorly parked or stationary vehicles.
- If the availability of GNSS positioning cannot be ensured (e.g. through foliage or in tunnels), **additional reference points** may be required.
- **Charging infrastructure** and **parking space** are best protected (protection against vandalism).
- During some tests it appeared that a slightly increased **wear of** the road surface could be observed in the track of the shuttle. This can be limited by programming a **sway** in the driving behaviour of the autonomous shuttle.
- **Movement on the edge of** the footpath is sometimes interpreted as a risk.
- For **boarding** and **disembarking** passengers on public roads, an autonomous shuttle usually stops on the side of the road. It is possible that a few parking spaces will have to be sacrificed for this. Merging and exiting of the shuttle with other traffic is a complex operation. Stopping at a protruding stop on the carriageway is less complex and may be an option to be explored (acceptance, overtaking manoeuvres).

Chapter 4 Conclusion

In previous chapters, we looked at a multitude of aspects in the field of CAV[60]. The information collected provides insight into the possible consequences of CAV for the road infrastructure and the road authorities. We placed this in a social context. In this chapter we want to bring the main conclusions together. The structure is as follows:

[60] For the terminology used, see § 2.1 Description of CAV.

4.1 Introduction: brief **overview of the how and why** of the research;
4.2 **(Un)**certainty and complexity concerning CAV;
4.3 Social evolutions/policy, on the need for **policy research**, and the **societal aspects of** autonomous vehicles;
4.4 **Road infrastructure**: the '**no regret**' measures in the following areas:

- signage;
- road geometry;
- road structure;
- road surface.

4.1 Introduction

BRRC wished, on its own initiative, to conduct research into the **role of the physical road infrastructure** in the development of self-driving vehicles.

The **reason** for this research was the insight that many aspects of CAV are being studied and receive a great deal of attention, but also the feeling that the aspect of 'physical road infrastructure' has so far received only scant attention.

For **road authorities**, it is important that they are well armed to take up the challenge and create the conditions that will enable the gradual transition to autonomous vehicles of higher SAE levels (e.g. adapted or easily adaptable infrastructure). At the same time, the data made available by the deployment and use of these vehicles can contribute to the tasks that road authorities have to perform (e.g. road management, road safety and traffic management). The focus of road authorities should continue to be on **road infrastructure**, but at the same time be extended to **digital infrastructure**, communication and geolocation. In addition, the use of the road through different modes and for different travel motives has their attention.

On the other hand, **contractors** also need to be prepared for the changes this will bring about in various areas, such as modifications to the road and road environment, and communication of the road works.

The working group set up by BRRC consisted of **experts** from various organisations, each of whom was able to contribute from their own expertise to discussions on the research topic outlined. Fascinating **knowledge exchanges** took place during the meetings of the working group.

Together with a screening of relevant **literature** (+215 documents), the discussions led to the present document. Here you will find a state of affairs and a foresight in the field of CAV and road infrastructure.

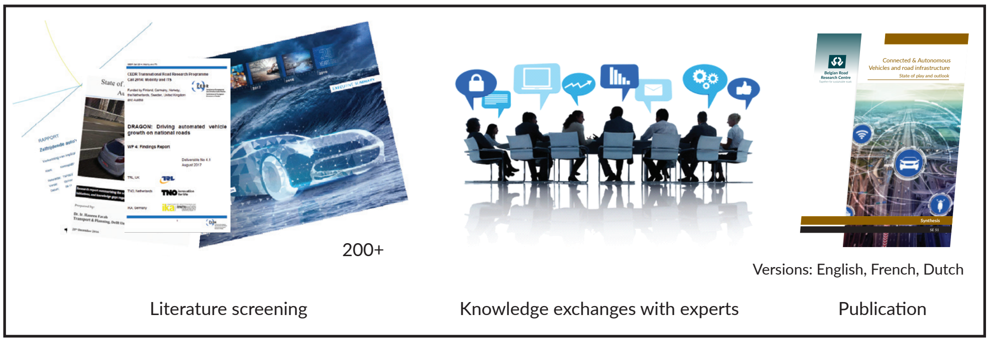

Figure 4.1 – *Realisation of the publication 'CAV & road infrastructure – state of affairs and foresight'*

The document contains **conclusions** that are likely to apply several years after the publication of this report. Our aim here is to provide insight into '**no regret**'-road infrastructure measures. However, we cannot avoid sketching the **bigger picture**: although road infrastructure is an essential prerequisite for transport, it obviously has close interfaces with other aspects of society and the transport system in particular.

4.2 (Un)certainty and complexity

On the basis of the literature and discussions, we can state that our journeys over the coming decades will be characterised by a **mix of** public services and private means of transport, and by a wide **variety of connectivity and degrees** of vehicle **autonomy**.

A possible final picture – a society with 100 % connected journeys (of all types of road users) and autonomous vehicles of only SAE level 5 – remains **far away** for the time being. The necessary changes are so far-reaching that the road to such a society is paved with numerous uncertainties. Balancing the pros and cons[61], timing and development of technologies[62], rules / roles / responsibilities (for drivers, vehicles, road authorities, policy authorities, etc.), social acceptance and ethical issues: **important steps** still need to be taken in these areas.

61 § 2.2 Objectives.

62 § 2.4 Roll-out CAV & obstacles.

In the coming decades with various levels of autonomy (SAE levels) and connected and unconnected journeys, the practical details of the steps to be taken are not yet clear. For road authorities, it is a matter of continuously acquiring knowledge about **advancing insights**, in order to remove the uncertainties.

We can speak of a general consensus that the gradual introduction of autonomous vehicles is **complex**:

- The development of autonomous vehicles is only one of the **challenges** road authorities are facing. § 3.3 elaborates, in random order, on the challenges in the **urban context**: emerging micromobility, sharing systems, greening of transport, adaptation of speed limits, digital infrastructure, commitment to slow mobility and accessibility, and diversification of public transport services.
- Autonomous vehicles have the potential to bring about **major changes and innovations** to the **entire transport system**. CAV admitted on public roads are vehicles that must have passed an approval procedure, taking into account the road infrastructure.
- However, a lot of questions remain:
    - What policy (local, national) on passenger and freight transport could be used to bring about this change? By what deadline? And in which locations?

  - Which price are we willing to pay to change and renew the transport system? What is the desirability of that development[63]?

- With regard to **road infrastructure**[64]:

  - What measures can or should be taken now?
  - What coordination or distinction can be made according to type of road, type of means of transport, level of technological development (SAE levels)?
  - Who will be allowed or able to drive where?

[63] § 4.3 Social evolutions / policy.

[64] § 2.4.1 Road infrastructure.

4.2.1 Foresight and risk management

In view of the uncertainties, it is recommended that road authorities pay more attention to **foresight** and **risk management** when planning the transport system.

Foresight is hugely important. It is desirable for road authorities to think in **scenarios**, with a long-term horizon (10 years and more) on the one hand and to keep an eye on uncertainties and the over- and underestimation of development opportunities on the other. It is then advisable to act **pragmatically**: focus mainly on 'no regret' measures for the coming lustrum, and in the course of time adjust the actions as a function of new insights[65].

[65] § 2.4.3 Foresight.

Risk management can be a major asset. This is an ongoing process and an essential part of project management. Specifically towards CAV: risk management has been included in the Code of Conduct for testing in Belgium[66]. **Scenario-based planning** could help to better anticipate the future. This type of planning starts from the idea that an organisation accepts multiple scenarios, each of which has the potential to become reality in the future (CFO Editing, 2016). In the so-called **decision-oriented planning approach**, dealing with uncertainty occupies an important place in the transformation of situations into choice situations. Supporters of this approach embrace uncertainty, taking into account gaps in knowledge, changing value patterns and unknown effects on measures to be taken in the future (Faludi, 1973).

[65] § 5.3.1 Belgium.

4.2.2 Research for testing

Progressive insight is nourished by doing research. The research agenda for the roll-out of autonomous vehicles is richly filled. In all areas of uncertainty, an answer can only be found by conducting research and **testing**.

Many tests are taking place on **autonomous shuttles**, which can complement more traditional forms of public transport.

The current state of affairs is that there is **no business case yet**. This does not prevent public transport organisations from initiating or continuing tests.

The tests usually first take place in relatively simple situations, in environments where confrontation with other road users is limited, and at limited speeds. For example, a park, a pedestrian zone, a campus with little transport. Gradually, the shuttles are made to drive around in more complex situations, such as on public roads. Road authorities are an unavoidable partner in supporting test projects with CAV. In view of the complexity, this is a step-by-step approach and progressive insight in which vehicle technology, infrastructure redrawing and adaptation of regulations go hand in hand.

Figure 4.2 – *Autonomous pedestrian shuttle test in Masdar City, Abu Dhabi, October 10, 2019*

Figure 4.3 – *Trilingual warning sign in use during the test of the self-driving shuttle in Neder-over-Heembeek, February 12, 2020*

Road authorities should be expected to play a role in **tests** with vehicles other than autonomous shuttles, both in preparation and execution. They have relevant **information** about **their road network** at their disposal, in terms of use (means of transport, travel motives, susceptibility to congestion, unsafe behaviour, etc.) and infrastructure (road design, layout and signing, intrinsic road safety, infrastructural choices, maintenance needs, etc.).

They can **confront** this **practical knowledge** with **ODD** (Operational Design Domain)[67] proposed by researchers, the description of the specific operational domains for which an automated function or system is designed to work properly. It is partly up to (local) road authorities to assess how and where the tests can be carried out in practice.

[67] ODD / Operational Design Domain: the specific conditions under which a particular drive automation system or a feature thereof is designed to operate, including, but not limited to, driving modes. This may include various restrictions such as geography, traffic, speed and roads (Lemecjava, 2016).

Testing different **use cases** is necessary. An interesting case is that of the road works. Particular attention should be paid to unconnected road users.

For supra-local road authorities, participation in the **development of the ODD** itself is crucial. This is possible by participating in international working groups and research projects, or at least by following up those initiatives. With the further development of the ODD, further attention will be paid to transitions between zones or road sections of different **ISAD** levels (Levels of Infrastructure Support for Automated Driving).

Attention is drawn to the following **factors**:

Type of road or road section	For which type of road has a certain function or level of automation been developed?
Time	During which periods can a certain level of automation be supported by a road section?
Weather	In what weather conditions can the different levels of automation function?
Traffic	What is the influence of the volume and type of traffic on the supported automation levels?

Table 4.1 – *Some factors that determine the Operational Design Domain*

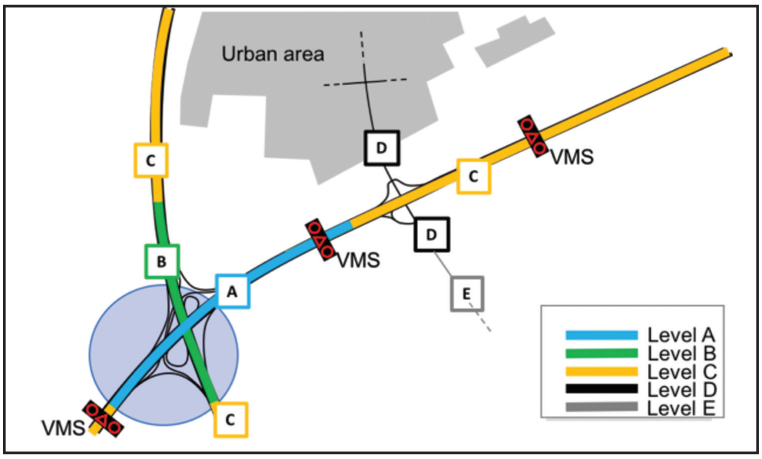

Figure 4.4 – *Example of ISAD levels assigned to a road network (Inframix, 2017) of affairs and foresight'*

4.3 Social evolutions / policy

The added value of autonomous vehicles in a future sustainable mobility policy is a fascinating theme. The potential to use autonomous vehicles as a **lever** for a 'different mobility' is put forward by some experts as a possible solution to current mobility problems (congestion, traffic safety, environmental pollution). Possibly society is facing drastic changes. Some cities participate pragmatically in test projects and take part in the evaluation.

A far-reaching successful introduction of CAV requires, on the one hand, a continuation of policy research and evaluations of projects. On the other hand, insight into the social aspects of autonomous vehicles and the related digitisation of society is useful.

4.3.1 Policy research and evaluations of projects

Research into the cost & benefit of introducing autonomous vehicles into the transport system is relevant:

- Policy documents contain different objectives with advantages and disadvantages[68]. There is often a lack of objective results, and there are contradictions. It is the task of researchers, with the cooperation of road authorities, to carry out analyses, to reduce uncertainties and add nuances. The additional research can also provide a **more realistic picture** of the expectations about autonomous vehicles.
- The **involvement of citizens** is a crucial aspect in the **coordination** between road authorities, car manufacturers (vehicle functionalities), and digital service providers in research projects. This concerns both the end user (the persons using autonomous vehicles) and those who encounter the autonomous vehicles on the (public) road (especially: pedestrians and cyclists, whether or not they are connected). **Acceptance** of autonomous vehicles by users and not users is an essential area of research.
- **Projects** with CAV can also be evaluated at mid-term. These **evaluations** can lead to adjustments of the project and influence future projects. Concrete actions and options for the road authorities can be derived from this. Alignment with policy plans is a concern.

[68] § 2.2 Objectives.

4.3.2 Society

Research is still needed in many areas: research for testing[69] and policy research (see above). A **more existential** approach is also appropriate. It is more a social mission than a technological question (Society beats technology), with essentially complex questions such as:

69 § 4.2 (Un)certainty and complexity.

- What kind of society do we want to strive for? What kind of cities do we want to live in? With a lot of regulation or a lot of freedom ('state vs. market')? With an emphasis on collective or individual transport, or a mix of these? How to deal with regional differences?
- How realistic is a development in which private cars are increasingly restricted? Will there be cities that choose for a ban? Or, are there cities that are abolishing the reserved lanes (public transport)?
- What requirements should we set for the use of robotaxis?

This is about **focusing on possible futures** for society as a whole. This includes, among other things:

- Involving relevant stakeholders in defining policy (e.g. mobility plans). This can be done through **co-creation**, a form of collaboration in which all participants influence the outcome of a process and the path towards it.
- The considerations to be taken into account are in particular accessibility, quality of life, safety and inclusiveness. The **inclusive thinking** around the development of autonomous vehicles can ensure that due account is taken of active road users (whether or not they are connected).
- A **debate** on the use of space by different modes of transport, the need for alternatives, and accessibility still needs to continue.
    - It is about the question of who is still allowed to use road infrastructure where and when.
    - In the extreme case, it is about access to the city.
    - This requires scenario building[70] with traffic models and stakeholder consultation. The scenarios should include combinations of private cars (electric or otherwise environmentally friendly), traditional public transport, additional shuttle services, robotaxis, active means of transport and micromobility.
    - Attention to the parking issue is very important here, is parking cheaper than driving around? If so, what rules are needed? Are there restrictions per type of vehicle?
- The study of '**best case**' and '**worst case**' **scenarios** in the field of mobility related aspects (accessibility, traffic safety, quality of life). Several studies (Backhaus, 2020; ITF, 2015) indicate that an unbridled introduction of autonomous vehicles could lead to more traffic. The question here is twofold: who can do what to mitigate negative effects, and what measures can be taken to make the best case scenario the most likely?

70 § 4.2 (In)certainty and complexity.

4.4 Road infrastructure

The original intention of the text was to consider whether certain adaptations to infrastructure are necessary or useful to enable or facilitate the gradual transition to self-driving vehicles. Logically, the requirements that self-driving vehicles place on infrastructure are highly dependent on the environment in which they operate. For this reason, we split up the text into motorways and urban environments. We added a section on shuttles, for which the tests mainly take place in a limited environment.

Since, for most vehicles, drivers will continue to carry out certain actions and corrections themselves for a considerable time, **recommendations for the design of traffic infrastructure** (road geometry, road environment, signage, road surface quality and durability) will have to continue to take these human drivers into account for some time to come.

Nevertheless, automotive manufacturers, legislative initiatives, expected vehicle fleet evolutions and testing experiences seem to indicate that **road infrastructure** will require **adaptations** to facilitate self-driving vehicles. By already considering these expectations in the (re)construction of road infrastructure, later adaptations may become easier. In any case, the needs most emphasised by car manufacturers today (visibility and harmonisation of signage) also make sense for human drivers.

Road authorities have traditionally paid attention to physical infrastructure. However, the introduction of self-driving vehicles introduces **new areas** that road authorities should also look at. A digital representation of physical infrastructure (**digital twin**) can be used for guidance systems or as a complement or alternative to signage. If GNSS positioning (GPS, Galileo, etc.) is unavailable or insufficiently accurate, physical beacons may become useful to enable (more accurate) positioning. For the exchange of data, road infrastructure will need to be complemented by **communication infrastructure**.

4.4.1 Signage

Road markings, road signs, variable message signs, traffic lights and other signing systems serve to convey a message to drivers of vehicles. If vehicle systems support the driver or take over his driving task, it is important that this message is also **accessible** to these vehicle systems, and then understood by drivers. There are currently a number of options that can complement each other or serve as a backup if one of the options is (temporarily) unavailable.

Cars equipped with sensors shall be able to **recognise** and **interpret** signs. This involves many aspects: signs must be detectable, visible and readable in all circumstances. The message must also be understandable and unambiguous.

In the case of the lower automation levels, this information will be shown to the driver, who will then be deemed to react appropriately. In the higher levels of automation, algorithms can interpret these messages and actively intervene in the driving behaviour of the car.

In all cases, it is important that sensors are able to distinguish these messages and then interpret them correctly. Measures that increase the **visibility of road signs or road markings**, even in less optimal conditions, can certainly contribute to this.

- Harmonisation and simplification of these messages will make it easier for vehicle systems to correctly interpret[71] the detected message;
- European initiatives on signing facilitate the arrival of internationally accredited CAV. Road signs and road markings that are insufficiently recognizable and differences by country or region increase the risk that CAV does not recognize or understand[72] them;
- In addition to being useful for vehicle systems, human drivers also benefit from uniform and clearly visible messages. Language-specific messages should be avoided as much as possible.

[71] In the UNECE Group of Experts on Road Signs and Signals (part of WP on Road Traffic Safety, *https://www.unece.org/trans/main/welcwp1.html*) an attempt is being made to harmonise signs.

[72] The EC Expert Group on Road Infrastructure Safety (*https://ec.europa.eu/transparency/regexpert/index.cfm?do=groupDetail.groupDetail&groupID=3686*) examines whether minimum visibility features for signing can contribute to the deployment of self-driving vehicles.

If vehicle sensors are unable to recognise traffic signs or road markings correctly, this may be interesting information for road authorities. Connected systems can pass on locations where signs are insufficiently recognisable to road authorities. They can use that information as an alternative to visual inspections and to plan maintenance more efficiently. The exchange of vehicle data with road authorities can thus contribute to better road infrastructure, both for self-driving vehicles and for human drivers.

Alternatively or in addition to sensors, automated vehicles can also receive messages via **connected systems**.

- A digital representation of physical infrastructure essentially consists of a **detailed (digital) map** enriched with information about the road environment and the applicable (possibly dynamic) traffic rules.
- Via communication systems, the map can be made available in the vehicle or stored information can be updated. In such systems, it is important that changes to the infrastructure or incidents affecting the expected driving behaviour get into the vehicle in real time. An important point of attention here is the data safety and security of the vehicle, as well as the operation of its functions.
- In the first instance, the state of infrastructure will probably be mapped by human intervention. **Contractors** who change the **road configuration** during road works can be asked to pass on these changes. This must be part of the assignment. Limited applications already exist today that allow road users to pass on information about the road infrastructure to the road administrator (e.g. via special apps). In the future, new developments and digitisation in the field of road condition measurement and road inventory may also allow vehicle systems to use observations for more accurately mapping the state of road infrastructure[73].

[73] E.g. *www.xenomatix.com*. On the basis of LIDAR technology, the technical parameters that can be measured (longitudinal evenness, transverse evenness, visual inspection, recognition of markings on the road, etc.) are examined. In the long term it would be possible to collect these parameters by crowd-sourcing (if this technology is in autonomous vehicles).

Signing can also be equipped to communicate directly with vehicle systems. **Traffic lights** and **variable message signs** in Flanders are already provided with this option as standard today or to be added later. Standardized communication protocols are currently being discussed internationally.

4.4.2 Road geometry and road layout

Several publications **suggest** that a 100 % reliable and fully automated vehicle fleet will allow for the adaptation of the road geometry recommendations. Recommendations for the geometry related to the overview on the road for human drivers will then play a less compelling role. Roads could then be more in line with the natural course of the terrain.

The capacity of the roads becomes higher, not because of the different geometry, but because of a higher occupancy (more homogeneous speed and smaller spacing)[74]. Ultimately, a situation with SAE L5 vehicles alone could even lead to narrower lanes (with less safety margin) and roads with increased capacity for the same occupation/occupancy of space (or new roads with less space occupancy for the same capacity).

[74] § 2.2.7 Road capacity.

However, it is **unlikely** that **only fully automated vehicles** will be on the road in the near future. At the moment, it is unclear how incidents will be handled in a traffic system with automated vehicles. Will this be possible in a safe way with the current (or in a distant future adapted) road layout or will automated vehicles continue to rely on certain infrastructure (lay-bys, sufficient space for intervention vehicles between vehicles in two adjacent lanes) to handle incidents in a safe way? However, we can assume that fully autonomous vehicles will only be homologated if there are agreements on what infrastructure these vehicles can rely on to handle incidents safely.

It is therefore best to **retain** all of today's **recommendations** for road geometry. By already considering future modifications during (re)construction, major works can be limited to a certain extent at a later stage.

- To enable for example (later) use of alternating lanes or dynamic lane layout, it can be considered to avoid **physical separation** as much as possible, of course always taking into account existing **road safety** recommendations.
- The widths of **emergency stopping lanes** can be adjusted so that they can easily be converted into a rush-hour lane or a fully-fledged lane at a later date.
- At entrances and exits or at **auxiliary lanes**, space can be provided for later expansion for automated traffic and the facilitation of weaving movements.

4.4.3 Road structure

For the time being, it is uncertain whether **future vehicles** with other propulsion will be lighter or heavier. Based on the current evolution of the mass of new cars, the expected increase in traffic and the estimation that future vehicle systems may allow a more efficient use of existing road capacity, it seems likely today that the **occupancy of a road**, both by passenger cars and by freight traffic, will only increase in the future.

That higher occupancy is likely to affect the **loads** on a road structure. An update of the traffic spectrum (taking into account recent or expected vehicle characteristics) and an estimation of the amount of traffic over the expected lifetime (taking into account a possibly changing road occupancy) may give rise to different road design requirements. In addition, due to higher occupancy rates, **unavailability of a road** due to road works or accidents will inevitably have a greater impact on mobility.

Road structures that are better able to withstand higher loads and fast repair techniques only seem to increase in importance. In any case, **ordinary road users** also benefit from this.

4.4.4 Road surface

The current generation of **vehicle sensors** and **algorithms** can detect road surface defects with varying degrees of success and handle them successfully. Larger surface defects remain a problem for the time being and already cause a self-driving vehicle (in this case a shuttle) to stop.

Defects on the side of the road can cause difficulties in positioning an AV on its lane (Van Geem et al., 2020)

Bitumen deposition/bleeding/ longitudinal joints can (e.g. in bad weather conditions) be detected incorrectly as lane boundaries (*Ministerie van de Vlaamse Gemeenschap [MVG], Administratie Wegen en Verkeer [AWV] & Opzoekingscentrum voor de Wegenbouw [OCW]*, 2001)

Figure 4.5 – *Surface defects may hinder the functioning of self-driving vehicles*

In addition, the road surface also plays a role in **energy consumption** and **driving comfort**. Both aspects are not exclusively linked to self-driving vehicles, but are becoming more important for electric vehicles (range, consumption) and for the passengers of self-driving vehicles (e.g. shuttles).

For the time being, it does not seem necessary to tighten up the existing recommendations for road surfaces. On the other hand, it does make sense to ensure that the **expected road surface quality** is effectively achieved and maintained. In this respect, it makes sense to focus on high-quality and durable repair techniques.

Chapter 5
Background info

5.1 Relevant regulations

5.1.1 Europe

See table on page 66.

5.1.2 Belgium

See table on page 67.

Table 5.1 – *Relevant regulations (Europe)*

				Type of legislation	Legislation	Description	Link
EU LEGISLATION		The European ITS directive		Framework directive	2010/40/EU	Describes the framework within which intelligent transport systems should be rolled out in the road traffic domain, as well as the interfaces with other transport modes. The Directive contains 4 priority areas and 6 priority actions. Each indicates the priorities put forward by the European Commission. EU Member States are obliged to report periodically on the progress of implementation. Some items are imposed by the EU, for others, if the Member State wants to implement this service, one is bound by a predefined working method.	*https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32010L0040*
EU LEGISLATION	6 ITS directive Priority actions	**a**	Multimodal Travel Information Services (MMTIS)	Delegated Regulation	2017/1926	Describes what needs to be achieved with regard to the provision of EU-wide multimodal travel information services.	*https://eur-lex.europa.eu/eli/reg_del/2017/1926/oj*
EU LEGISLATION	6 ITS directive Priority actions	**b**	Real-Time Traffic Information Services (RTTI)	Delegated Regulation	962/2015	Describes what needs to be achieved with regard to the provision of EU-wide real-time traffic information services.	*https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32015R0962*
EU LEGISLATION	6 ITS directive Priority actions	**c**	Road safety related minimum universal traffic information free of charge to users (SRTI)	Delegated Regulation	886/2013	Describes the necessary data and procedures for the provision, where possible, of road safety-related minimum universal traffic information free of charge to users.	*https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32013R0886*
EU LEGISLATION	6 ITS directive Priority actions	**d**	eCall	Delegated Regulation	305/2013	Describes how the harmonised provision for an interoperable EU-wide eCall Text should take place.	*https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32013R0305*
EU LEGISLATION	6 ITS directive Priority actions	**e**	Information services for safe and secure parking places for trucks and commercial vehicles	Delegated Regulation	885/2013	Describes how information services for safe and secure parking places for trucks and commercial vehicles should be provided.	*https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32013R0885*
EU LEGISLATION	6 ITS directive Priority actions	**f**	Reservation services for safe and secure parking places for trucks and commercial vehicles		On hold	Developments towards a Delegated Regulation on reservation services for safe and secure parking places for trucks and commercial vehicles were put on hold due to lack of interest from Member States.	
EU LEGISLATION	EU cybersecurity Act			Regulation	2019/881	The EU Cybersecurity Act revamps and strengthens the EU Agency for cybersecurity (ENISA) and establishes an EU-wide cybersecurity certification framework for digital products, services and processes.	*https://eur-lex.europa.eu/eli/reg/2019/881/oj*
EU LEGISLATION	General Data Protection Regulation			Regulation	2016/679	Regulation on the protection of natural persons with regard to the processing of personal data and on the free movement of such data.	*https://eur-lex.europa.eu/eli/reg/2016/679/oj*
EU LEGISLATION	Revised General Safety Regulation			Regulation	2019/2144	Type-approval requirements for motor vehicles and their trailers, and systems, components and separate technical units intended for such vehicles, as regards their general safety and the protection of vehicle occupants and vulnerable road users.	*https://eur-lex.europa.eu/eli/reg/2019/2144/oj*

Table 5.2 – *Relevant regulations (national)*

		Type of legislation	Legislation	Description	Link
Belgian legislation	Law creating the framework for the introduction of intelligent transport systems	Transposition of the framework directive	53-2943	This includes the transposition of the European framework directive into Belgian law.	*http://www.ejustice.just.fgov.be/cgi_loi/change_lg.pl?language=nl&la=N&cn=2013081735&table_name=wet*
Belgian legislation	Cooperation agreement on Directive 2010/40/EU between the Regions and the Federal Public Service Mobility	Cooperation agreement	C-2016/14240	Cooperation agreement on Directive 2010/40/EU of the European Parliament and of the Council of 7 July 2010 on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport.	*http://reflex.raadvst-consetat.be/reflex/pdf/Mbbs/2016/08/12/134026.pdf*
	Belgian code of practice for testing with (semi)-autonomous vehicles on public roads	Guideline (not legislation)	N/A	This is not legislation, but a guideline that defines roles and responsibilities as well as a way of working together for tests carried out on vehicles of higher levels of automation on public roads.	*https://mobilit.belgium.be/nl/wegverkeer/voertuigen_en_onderdelen/intelligente_vervoerssystemen_its/semi_autonome_voertuigen*
Flanders	Decree creating the framework for the introduction of intelligent transport systems	EU framework directive transposition	Publication: 2013-04-16 Numac: 2013035341	Decree on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport (1).	*http://www.ejustice.just.fgov.be/cgi/article_body.pl?language=nl&caller=summary&pub_date=13-04-16&numac=2013035341*
Flanders	Decision of the Flemish Government on the framework for the deployment of Intelligent Transport Systems	Decision of the Flemish Government	Publication: 24/07/2013 Numac: 2013035655	Decision of the Flemish Government on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport.	*http://www.ejustice.just.fgov.be/cgi/article_body.pl?language=nl&caller=summary&pub_date=13-07-24&numac=2013035655*
Flanders	Connected and automated mobility in Flanders	Bisconcept note (no legislation)	VR 2018 0203 DOC.0194/1BIS	Bisconcept note to the Flemish Government on CCAM.	*https://www.ewi-vlaanderen.be/sites/default/files/conceptnota_-_geconnecteerde_en_geautomatiseerde_mobiliteit_in_vlaanderen.pdf*

5.2 Definitions / Abbreviations

ABS	**A**nti-lock **B**raking **S**ystem
ACC	**A**daptive **C**ruise **C**ontrol
AD	**A**utomated **D**riving
ADAS	**A**dvanced **D**river **A**ssistance **S**ystem
AEB	**A**utonomous **E**mergency **B**raking
AEBS	**A**dvanced **E**mergency **B**raking **S**ystem
AI	**A**rtificial **I**ntelligence
AWV	**A**gentschap **W**egen en **V**erkeer (B)
BCR	**B**russels-**C**apital **R**egion
BIM	**B**uilding **I**nformation **M**odelling
CACC	**C**onnected **A**daptive **C**ruise **C**ontrol
CAV	**C**onnected and **A**utonomous **V**ehicles
CCAM	**C**onnected **C**ooperative **A**utomated **M**obility
CEDR	**C**onference of **E**uropean **D**irectors of **R**oads [CEDR]
C-ITS	**C**ooperative **I**ntelligent **T**ransport **S**ystems
C-ITS Day 1 Services	Agreed list of services with mature technology and expected societal benefits
C-ITS Day 1.5 Services	Mature and desired services which are still missing complete specifications and/or standards
DAS	**D**river **A**lert **S**ystems
DFM	**D**river **F**atigue **M**onitor
EDR	**E**vent **D**ata **R**ecorder

EV	**E**lectric **V**ehicle
GNSS	**G**lobal **N**avigation **S**atellite **S**ystem
GPS	**G**lobal **P**ositioning **S**ystem (US)
ISA	**I**ntelligent **S**peed **A**daptation
iTLC	**I**ntelligent **T**raffic **L**ight **C**ontrollers
ITS-G5	Short range communication on the 5.9 GHz band
KPI	**K**ey **P**erformance **I**ndicator
LDWS	**L**ane **D**eparture **W**arning **S**ystem
LED	**L**ight-**e**mitting **D**iode
LEZ	**L**ow **E**mission **Z**one
LKS	**L**ane **K**eeping **S**ystems
LKA	**L**ane **K**eeping **A**ssistance
LTE-V2X	**L**ong-**T**erm **E**volution **V**ehicular **T**o **X** (Competitive Communication Protocol)
MaaS	**M**obility **a**s **a** **S**ervice
MMTIS	**M**ulti**m**odal **T**ravel **I**nformation **S**ervices
NOx	**N**itrogen **O**xides
ODD	**O**perational **D**esign **D**omain
PM	**P**articulate **M**atter
PN	**P**article **N**umber
PRM	**P**ersons with **R**educed **M**obility (B)

PUDO	Zones for **P**icking **U**p and **D**ropping **O**ff passengers
RTTI	**R**eal-**T**ime **T**raffic **I**nformation **S**ervices
RWS	**R**ijks**w**ater**s**taat (NL)
RWW	**R**oad **W**orks **W**arning
SAE	**S**ociety of **A**utomotive **E**ngineers (US)
SAM	**S**hared **A**utonomous **M**obility
SDC	**S**elf-**D**riving **C**ar
SMMT	The **S**ociety of **M**otor **M**anufacturers and **T**raders Limited
SPW	**S**ervice **P**ublic de **W**allonie (B)
SRTI	**S**afety **R**elated **T**raffic **I**nformation
TMS	**T**raffic **M**anagement **S**ystem
V2I	**V**ehicle **t**o **I**nfrastructue
V2P	**V**ehicle **t**o **P**edestrian
V2X	**V**ehicle **t**o **E**verything
V2V	**V**ehicle **t**o **V**ehicle
VMS	**V**ariable **M**essage **S**igns
VWI	**V**ademecum **W**eg**i**nfrastructuur (AWV)
ZEZ	**Z**ero **E**mission **Z**one
5G	**5**th **G**eneration mobile network

Table 5.3 – *Abbreviations*

5.3 Testing: test sites & Living Labs (EU)

5.3.1 Belgium

In consultation with partners (regional public services, sector federations Agoria vzw and Febiac vzw, BIVV vzw (current: Vias Institute)), the FPS Mobility and Transport drew up a code of conduct for testing in Belgium in 2015/2016 (Federal Public Service Mobility and Transport, 2016b).

This code of conduct provides guidelines for organisations wishing to carry out tests with technologies for drivers assistance systems and automated vehicles on public roads or in other public places in Belgium. This Code of Conduct is intended for the following applications:

- Testing driver assistance systems and partially or even fully automated vehicle technologies on public roads or in other public places in Belgium;
- Testing a wide range of vehicles, from smaller automated pods and shuttles to the more traditional road vehicles such as cars, vans, buses or trucks.

Testing (not exhaustive list)

- E313 (B, associated with InterCor project);
- FORD test track in Lommel (B) indicated as potentially interesting for certain tests (in particular behaviour of vehicles on different road surfaces, vehicle probe data);
- Han-sur-Lesse shuttle bus (VIAS Institute & Federal Public Service Mobility and Transport, 2018);
- Navajo, Louvain-la-Neuve;
- Brussels Airport Company & De Lijn, Zaventem;
- SAM-e, Parc Woluwe / Solvay Campus / Brugmann Hospital;
- Maria Middelares Hospital, Ghent;
- UZ Brussels;
- VUB Hospital campus, Brussels.

5.3.2 Worldwide (overview)

- Shared Personalized Autonomous Connected vEhicles project (*https://space.uitp.org*) SPACE was launched by UITP in March 2018 with the aim of putting public transport at the heart of the automated vehicle (AV) revolution;
- The website gives an overview of existing tests and future concepts, divided into different habitats: rural - low density, small isolated city, suburban and urban (high density);
- *De Lijn*, STIB and the VUB are part of the 50 project partners (open to all partners of UITP).

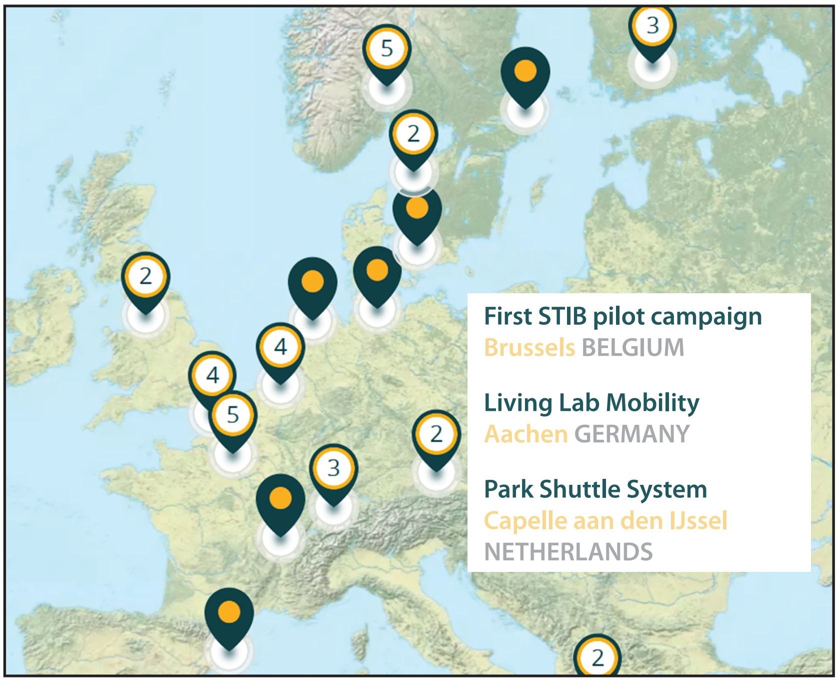

Figure 5.1 – *Extract from the Progress map of autonomous public transport initiatives (UITP, n.d.)*

5.3.3 Europe

- Cooperative C-ITS Corridor (A, D, NL, *https://intercor-project.eu*): Road Works Warning, Sensor Data from Vehicles;
- Dutch Integrated Test Site for Cooperative Mobility Setting (NL, Helmond): part of N270 and A270 equipped with detection and vehicle tracking cameras and ITS-G5 services;
- A9 Autobahn (D): Digital Motorway test bed. Testing of V2V and V2I technology;
- UK Cite (GB, *www.ukcite.co.uk*) public road equipped with relevant infrastructure and available for V2X communication testing;
- Corridor Rotterdam – Frankfurt/Vienna (NL & D, *http://c-its-korridor.de/*) RWW and use vehicle data for traffic management;
- New generation ParkShuttle in Rotterdam region (Capelle aan den IJssel), *https://www.2getthere.eu*;
- A12 in Tyrol (A): Testing of Cooperative Systems;
- AstaZero (S, *www.astazero.com*) dedicated test site which simulates different traffic environments (highway, urban, rural) and which allows to simulate different traffic scenarios and incidents;
- Stora Holm test site (S, *www.storaholm.se*);
- DriveMe (S): Volvo project on the Gothenburg ring road (suburban, 70 km/h, no pedestrians, many separate traffic flows). No specific installations, testing of driving support systems (ADAS, no connectivity);
- Tre VTT (FIN, *www.vttresearch.com*) focuses on automation scenarios in urban environments;
- Nordicway (DK, *http://vejdirektoratet.dk/EN/roadsector/Nordicway/Pages/Default.aspx*) testing of C-ITS services;
- Shuttle bus La Défense, Paris (F, *https://www.transportshaker-wavestone.com/la-navette-autonome-la-conquete-de-la-defense/*);
- Shuttle bus Lyon, (F, *https://www.keolis.com/en/our-services/transport-solutions/autonomous-shuttles*);

- Transpolis (F, *www.transpolis.fr*) new test site with simulated urban environment to test new technologies;
- Scoop (F, *https://ec.europa.eu/inea/en/connecting-europe-facility/cef-transport/2014-eu-ta-0669-s*) with 3 000 communicating vehicles on 2 000 km of interconnected roads, validation of C-ITS services;
- Siscoga (E, Spanish test site).

5.3.4 Projects

- Arcade platform, *https://knowledge-base.connectedautomateddriving.eu/*;
- Avenue, Autonomous vehicles for Public Transportation Services, *https://h2020-avenue.eu/;*
- CoEXist, Working towards a shared road network, *https://www.h2020-coexist.eu/*;
- Concorda, Connected Corridor for Driving Automation, *https://connectedautomateddriving.eu/project/concorda/*;
- DIRIZON, *https://www.dirizon-cedr.com/*;
- DRAGON, DRiving Automated Vehicle Growth On National roads, *http://www.cedr-dragon.eu/*;
- Inframix, *https://www.inframix.eu/*;
- Intercor, Interoperable Corridors deploying cooperative intelligent transport systems, *https://intercor-project.eu/*;
- Levitate, Societal Level Impacts of Connected and Automated Vehicles, *https://levitate-project.eu/*;
- Mediator, *https://www.swov.nl/en/news/mediator-european-research-autonomous-vehicles;*
- RIMA, Robotics for Inspection and Maintenance, *https://rimanetwork.eu/*;
- Skillful, *http://skillfulproject.eu/*;
- STAPLE, Site Automation Practical Learning, *http://www.stapleproject.eu/*;
- TransAID, Transition areas for infrastructure-assisted driving, *https://www.transaid.eu/*;
- Drive 2 the future, *http://www.drive2thefuture.eu/*;
- SHOW, SHared automation Operating models for Worldwide adoption, *https://show-project.eu/*;
- Autonomous Shuttle Service for the Brussels Health Campus, *http://www.avlab.brussels.*

Figure 5.2 – *Test self-driving shuttle at Brussels Health Campus (Vrije Universiteit Brussel [VUB], 2019)*

Chapter 6 Literature

3M. (2019, May 15). Machine vision and contrast: How automated vehicles see the roads. *Intertraffic*. Retrieved from *https://www.intertraffic.com*

Ackermann, T. (2017, November). *The MEGAFON study and PTO's future roles*. Presentation for the Progress event of Mobility 4.0: Public transport at the heart of the transition, Brussels, Belgium. Retrieved from *http://www.stib-mivb.be/irj/go/km/docs/resource/Presentations/RDV-2017/Till-Ackermann.pdf*

Adapting infrastructure for a driverless future. (2016, October 1). *WSP*. Retrieved from *https://www.wsp.com/en-GL*

Adventure Cycling Association. (n.d.). *Road weary: When technology & engineering fails cyclists* [Presentation]. Retrieved from *https://ecf.com/sites/ecf.com/files/Sullivan.V_Road_Weary_When_Technology_and_Engineering_Fails_Cyclists.pdf*

Albright, B. (2017, March 7). Self-driving vehicles will impact service, logistics industries. *Field Technologies Online*. Retrieved from *https://www.fieldtechnologiesonline.com/*

Alpha SQUAD official. (2018, September 12). *BMW self riding motorcycle: BMW autonomous driving bike/BMW self riding bike/BMW R 1200 GS* [Video]. YouTube. *https://www.youtube.com/watch?v=XMuMoZlVYqs*

Ambrosius, E. (2018, December). *Autonomous driving and road markings*. Presentation for the IRF & UNECE ITS event on governance and infrastructure for smart and autonomous mobility, Geneva, Switserland. Retrieved from *https://www.unece.org/fileadmin/DAM/trans/doc/2018/wp29grva/s1p5._Eva_Ambrosius.pdf*

Arcadis. (2018). *Citizens in motion: Who's driving your future?*. Retrieved from *https://www.arcadis.com/en/global/our-perspectives/connected-and-autonomous-vehicles/citizens-in-motion/*

Autonome voertuigen: Nieuw paard van Troje? [Blog post]. (n.d.). Retrieved from *https://www.mobiel21.be/blog/autonome-voertuigen*

Backhaus, W. (2020, March). *Strengthening capacities of road authorities to plan for the transition phase of co-existence of conventional and connected and automated vehicles*. Presentation on the joint dissemination of H2020, CEDR projects and other initiatives related to CAVs and infrastructure event, Brussels, Belgium. Retrieved from *https://www.fehrl.org/*

Bannon, E. (2016, November 13). Lessons from Norway's electric surge. *Transport & environment (TE)*. Retrieved from *https://www.transportenvironment.org*

Besluit van de Vlaamse Regering van 5 juli 2013 betreffende het kader voor het invoeren van intelligente vervoerssystemen op het gebied van wegvervoer en voor interfaces met andere vervoerswijzen. (2013, July 24). (Numac No 2013035655). Retrieved from *https://www.etaamb.be/nl/index.html*

Blue Planet Studio. (n.d.). *Concept de technologie de transport intelligente pour le futur trafic automobile sur route: Le système intelligent virtuel effectue une analyse numérique de l'information pour connecter les données du véhicule sur la rue de la ville: Innovation futuriste* [Stockfoto]. Shutterstock. Retrieved from *https://www.shutterstock.com/fr/image-photo/smart-transport-technology-concept-futurecar-1784203961*

Bösch, P.M., Becker, F., Becker, H. & Axhausen, K.W. (2018). Cost-based analysis of autonomous mobility services. *Transport policy, 64*, 76-91. Retrieved from *https://doi.org/10.1016/j.transpol.2017.09.005*

Brown, T. (2018). The last mile to automation: How autonomous vehicles could solve the last mile delivery problem. *IT chronicles*. Retrieved from *https://itchronicles.com*

Brussels Airport & De Lijn. (2018, April 20). *Brussels Airport en De Lijn starten proefproject met zelfrijdende bus: Begin 2020 test op terreinen luchthaven* [Press release]. Retrieved from *https://delijn.prezly.com/brussels-airport-en-de-lijn-starten-proefproject-met-zelfrijdende-bus*

Brussels-Capital Region. (2019). *Plan énergie climat 2030: The right energy for your Region* (final version). Retrieved from *https://leefmilieu.brussels/sites/default/files/user_files/pnec_rbc_fr.pdf*

Brussels Mobilty. (2019, October 24). Good Move: Les premiers résultats de l'enquête publique sont là!. *Good Move*. Retrieved from *https://goodmove.brussels/fr*

Brussels Mobility, VIAS Institute & Wikibus. (2017, October). *Workshop véhicules autonomes: Synthèse, Spa-Francorchamps, Belgium*. Retrieved from *https://goodmove.brussels/fr/orientations/*

Bureau for Standardisation (NBN). (2002-2010). *Road restraint systems* (NBN EN 1317[-1-3]: 2010; NBN ENV 1317-4: 2002). Brussels: Author.

Bureau for Standardisation (NBN). (2019). *Passive safety and support structures for road equipment: Requirements and test methods* (NBN EN 12767: 2019). Brussels: Author.

BV. (2020, April 22). Stuttgart schaft dieselverbod af: Hoe corona een boom onder de lage-emissiezone legt. *Auto55*. Retrieved from *https://www.auto55.be/*

C-ITS Platform. (2016). *C-ITS Platform: Final report*. Retrieved from *https://ec.europa.eu/transport/sites/transport/files/themes/its/doc/c-its-platform-final-report-january-2016.pdf*

Carlson, P. (2019, January 1). How automated vehicles will change pavement marking. *ForConstructionPros.com*. Retrieved from *https://www.forconstructionpros.com*

Carreras, A., Daura, X., Erhart, J. & Ruehrup, S. (2018, September). *Road infrastructure support levels for automated driving*. Paper for the 25th ITS world congress on quality of life, Copenhagen, Denmark. Retrieved from *https://www.inframix.eu/wp-content/uploads/ITSWC2018-ASF-AAE-Final-paper_v4.pdf*

Carter, J. (2019, October 30). Zombie technologies of electric vehicles: Wireless charging. *Electric autonomy Canada*. Retrieved from *https://electricautonomy.ca*

CFO Redactie. (2016, May 27). Scenario-based planning: De grip op onzekerheid versterken. *CFO*. Retrieved from *https://cfo.nl*

Chen, F., Balieu, R. & Kringos, N. (2017, June). *Sustainable implementation of future smart road solutions: A case study on the electrified road*. In A. Loizos, I.L. Al-Qadi & A. Scarpas (Eds.), Proceedings of the 10th international conference on the bearing capacity of roads, railways and airfields (BRRCA 2017), Athens, Greece (pp. 2201-2207). Boca Raton, USA: CRC Press.

Clapaud, A. (2017, May). *Qui dit voiture autonome dit route intelligente*. L'atelier BNP Paribas: Smart city. Retrieved from *https://www.aitf.fr*

Claeys, T. (2018, November 27). Is er ruimte voor autonome voertuigen binnen stadslogistiek?: VIL onderzoekt potentieel van zelfrijdende voertuigen als pakjesbezorgers. *Value chain*. Retrieved from *https://www.valuechain.be/*

Clément-Werny, C., Belloche, S., Ferrando, J., Mathieu, Y. & Durand-Fleury, T. (2019). *Véhicules et mobilités autonomes: Quelles attentes citoyennes pour demain?* (Connaissances CEREMA). Bron, France: Centre d'Études et d'Expertise sur les Risques, l'Environnement, la Mobilité et l'Aménagement (CEREMA).

Commission Delegated Regulation (EU) No 305/2013 of 26 November 2012 supplementing Directive 2010/40/EU of the European Parliament and of the Council with regard to the harmonized provision for an interoperable EU-wide eCall. (2013). *Official journal of the European Union*, L 91, 1-4. Retrieved from *https://eur-lex.europa.eu/homepage.html*

Commission Delegated Regulation (EU) No 885/2013 of 15 May 2013 supplementing ITS Directive 2010/40/EU of the European Parliament and of the Council with regard to the provision of information services for safe and secure parking places for trucks and commercial vehicles. (2013). *Official journal of the European Union*, L 247, 1-5. Retrieved from *https://eur-lex.europa.eu/homepage.html*

Commission Delegated Regulation (EU) No 886/2013 of 15 May 2013 supplementing Directive 2010/40/EU of the European Parliament and of the Council with regard to data and procedures for the provision, where possible, of road safety-related minimum universal traffic information free of charge to users. (2013). *Official journal of the European Union*, L247, 6-10. Retrieved from *https://eur-lex.europa.eu/homepage.html*

Commission Delegated Regulation (EU) 2015/962 of 18 December 2014 supplementing Directive 2010/40/EU of the European Parliament and of the Council with regard to the provision of EU-wide real-time traffic information services. (2015). *Official journal of the European Union*, L157, 21-31. Retrieved from *https://eur-lex.europa.eu/homepage.html*

Commission Delegated Regulation (EU) 2017/1926 of 31 May 2017 supplementing Directive 2010/40/EU of the European Parliament and of the Council with regard to the provision of EU-wide multimodal travel information services. (2017). *Official journal of the European Union*, L272, 1-13. Retrieved from *https://eur-lex.europa.eu/homepage.html*

Concorda pilot Amsterdam in volle gang. (2019, September 30). *Praktijkproef Amsterdam*. Retrieved from *https://www.praktijkproefamsterdam.nl/actueel/nieuws/concorda-pilot-amsterdam-volle-gang*

Conference of European Directors of Roads (CEDR). (n.d.). *MANTRA: Making full use of automation for national transport and road authorities: NRA core business*. Retrieved from *https://www.mantra-research.eu/*

Continental. (2019, January 8). *Continental's vision: Seamless mobility combines autonomous shuttles and delivery robots* [Press release]. Retrieved from *https://www.continental.com/en*

Corot, L. (2017, July 11). Renault va faire communiquer la voiture avec les bornes de péage. *L'usine nouvelle*. Retrieved from *https://www.usinenouvelle.com*

Couplez, V. (2019, September 17). Les camions de chantier plus légers, plus sûrs et confortables: Évolution vers les véhicules mixtes de chantier. *InfraStructure*. Retrieved from *https://infrastructure.pmg.be/fr/home*

COWI & PTV Group. (2019). *The Oslo study: How autonomous cars may change transport in cities.* Retrieved from *https://www.cowi.com/about/news-and-press/new-report-how-self-driving-transport-will-affect-the-oslo-region*

Créer et gérer des emplacements de stationnement résevés: Le règlement de stationnement en Région de Bruxelles-Capitale. (2019). *La CeMathèque*, (49), 27. Retrieved from *http://mobilite.wallonie.be/home/centre-de-documentation/cematheque.html*

Decreet van 29 maart 2013 betreffende het kader voor het invoeren van intelligente vervoerssystemen op het gebied van wegvervoer en voor interfaces met andere vervoerswijzen. (2013, April 16). (Numac No 1013035341). Retrieved from *https://www.etaamb.be/nl/index.html*

Deelstep is door beperkte levensduur vervuilender dan andere transportmiddelen. (2020, March 10). *Het Laatste Nieuws (HLN)*. Retrieved from *https://www.hln.be*

Directive 2010/40/EU of the European Parliament and of the Council of 7 July 2010 on the framework for the deployment of intelligent transport systems in the field of road transport and for interfaces with other modes of transport. (2010). *Official journal of the European Union*, L207, 1-13. Retrieved from *https://eur-lex.europa.eu/homepage.html*

Dirnwöber, M. (2018, November). *Inframix: Road infrastructure ready for mixed vehicle traffic flows*. Presentation on the European conference on results from road transport research, Brussels, Belgium. Retrieved from *https://www.inframix.eu/wp-content/uploads/H2020RTR-nov-2018-INFRAMIX.pdf*

Dunkerley, F., Whittaker, B., Laird, J. & Daly, A. (2018). *Latest evidence on induced travel demand: An evidence review*. Retrieved from the Assets Publishing Service, UK Government website: *https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/762976/latest-evidence-on-induced-travel-demand-an-evidence-review.pdf*

Dutch Safety Board. (2019). *Who is in control?: Road safety and automation in road traffic*. Retrieved from *https://www.onderzoeksraad.nl/en*

Duvall, T., Hannon, E., Katseff, J., Safran, B. & Wallace, T. (2019, May 22). A new look at autonomous-vehicle infrastructure. *McKinsey & Company*. Retrieved from *https://www.mckinsey.com*

Erhart, J. (2018, September). *Road infrastructure support levels for automated driving*. Presentation at the 25th ITS world congress on quality of life, Copenhagen, Denmark. Retrieved from *https://www.inframix.eu/presentations/*

ERTRAC Working Group «Connectivity and Automated Driving». (2017). *Automated driving roadmap* (version 7.0, final). Retrieved from *https://www.ertrac.org*

EU wijst voorstel wifi-gebaseerde standaard voor verbonden auto's af. (2019, July 8). *Techzine*. Retrieved from *https://www.techzine.be*

European Automobile Manufacturers Association (ACEA). (2019). *Automated driving: Roadmap for the development of automated driving in the European Union*. Retrieved from *https://www.acea.be/uploads/publications/ACEA_Automated_Driving_Roadmap.pdf*

European Automobile Manufacturers Association (ACEA) & European Association of Automotive Suppliers (CLEPA). (2019). *Perspectives of the European automotive industry on future C-ITS spectrum needs for cooperative, connected and automated mobility* (ACEA-CLEPA Paper). Retrieved from *https://www.acea.be/uploads/publications/ACEA-CLEPA_paper-Spectrum_needs-November_2019.pdf*

European Commission (EC). (n.d.). *New safety features in your car*. Retrieved from *https://ec.europa.eu/docsroom/documents/34588/attachments/1/translations/en/renditions/native*

European Commission (EC). (2016a, April 19). *Digitising European industry: Reaping the full benefits of a digital single market* (Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions No COM[2016] 180, final). Retrieved from *https://eur-lex.europa.eu/homepage.html*

European Commission (EC). (2016b, November 30). *A European strategy on cooperative intelligent transport systems, a milestone towards cooperative, connected and automated mobility* (Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions No COM[2016] 766, final). Retrieved from *https://eur-lex.europa.eu/homepage.html*

European Commission (EC). (2018, May 17). *On the road to automated mobility: AN EU strategy for mobility of the future* (Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, the Committee of the Regions No COM[2018] 283, final). Retrieved from *https://eur-lex.europa.eu/homepage.html*

European Commission (EC). (2019). *Continuously open call for applications for the selection of members of the «single platform for open road testing and pre-deployment of cooperative, connected, automated and autonomous mobility»* (version 1.0). Retrieved from *https://ec.europa.eu/transport/modes/road/news/2019-02-26-call-applications-single-platform_en*

European Commission (EC), Innovation and Networks Executive Agency (INEA). (2019). *Automated road transport: On the way to connected and automated mobility: Horizon 2020*. Retrieved from *https://ec.europa.eu/inea/sites/inea/files/art_brochure-2019.pdf*

European Parliament resolution of 15 January 2019 on autonomous driving in European transport (No P8_TA[2019]0005). (2019). Retrieved from *https://www.europarl.europa.eu/doceo/document/TA-8-2019-0005_EN.pdf*

European Road Federation (ERF). (n.d.). *Recommendations to define the technical performance of road markings: Supporting scientific literature*. Retrieved from *https://erf.be/press-releases/recommendations-to-define-the-technical-performance-of-road-markings/*

European Road Transport Research Advisory Council (ERTRAC). (2019a). *Connected automated driving roadmap* (version 8). Retrieved from *https://www.ertrac.org*

European Road Transport Research Advisory Council (ERTRAC). (2019b, April 4). *Connected automated driving roadmap: 2019 update*. Presentation on the ERTRAC conference, Brussels, Belgium. Retrieved from *https://www.ertrac.org/uploads/images/ERTRAC2019-Connected-Automated-Driving-Roadmap%20-2019-04-04.pdf*

European Telecommunications Standards Institute (ETSI). (2019). *Intelligent transport system (ITS): Vulnerable road users (VRU) awareness. Part 1: Use cases definition: Release 2* (ETSI Technical Report No ETSI TR 103 300-1, V2.1.1). Retrieved from *https://www.etsi.org/deliver/etsi_tr/103300_103399/10330001/02.01.01_60/tr_10330001v020101p.pdf*

Faggella, D. (2020, March 14). The self-driving car timeline: Predictions from the top 11 global automakers. *Emerj*. Retrieved from *https://emerj.com*

Faludi, A. (1973). *Planning theory* (Urban and Regional Planning Series, 1st edition). Oxford: Pergamon Press.

Farah, H. (2016). *State of the art on infrastructure for automated vehicles: Research report summarizing the scientific knowledge, research projects, test sites, initiatives, and knowledge gaps regarding infrastructure for automated vehicles*. Retrieved from the TUDelft website: *https://repository.tudelft.nl/islandora/object/uuid:27b22b96-159b-4c45-bcca-b0fefc9969be?collection=research*

Federal Ministry of Transport, Innovation and Technology & Federal Agency for Technological Measures (austriatech). (2019, November). *Results report of the 4th high level meeting on automated & connected mobility «beyond SAE levels: Towards safe & sustainable mobility»*, Vienna, Austria. Retrieved from *https://www.austriatech.at/assets/Uploads/Publikationen/PDF-Dateien/9b75e638e4/High-Level-Meeting-on-Automated-and-Connected-Mobility-Report-2019.pdf*

Federal Public Service Mobility and Transport. (s.d.). *Personnes à mobilité réduite*. Retrieved from *https://mobilit.belgium.be/fr/pmr*

Federal Public Service Mobility and Transport. (2016). *Autonomous vehicles: Code of practice for testing in Belgium*. Retrieved from *https://mobilit.belgium.be/sites/default/files/resources/files/code_of_practice_en_2016_09.pdf*

Federal Service for Mobility and Transport (2020, February). *Legal framework for the introduction of autonomous buses in Belgium: Vision of the Federal Service for Mobility and Transport*. Presentation on the ITS.be workshop autonomous shuttles, n.l. Retrieved from *http://www.its.be/sites/default/files/SPF%20mobility.pdf*

Fernique, L. (s.d.). Grand livrable la vie robomobile 2018. *Mobilité intelligente (M3.0)*. Retrieved from *https://www.mobilite-intelligente.com*

Feys, M., Rombaut, E., Macharis, C. & Vanhaverbeke, L. (2020, November). *Understanding stakeholders' evaluation of autonomous vehicles in fleets of shared vehicles and integrated with public transport services in an urban setting* [Paper submitted for publication]. IEEE Forum on integrated and sustainable transportation system (ISTS 2020), Delft, The Netherlands.

Filippi, A., Moerman, K., Daalderop, G., Alexander, P.D., Schober, F. & Pfliegl, W. (s.d.). *Ready to roll: Why 802.11p beats LTE and 5G for V2x* [white paper]. Retrieved from *https://assets.new.siemens.com/siemens/assets/public.1510309207.ab5935c545ee430a94910921b8ec75f3c17bab6c.its-g5-ready-to-roll-en.pdf*

Frederik, Jesse. (2020, February 24). Your car has a weight problem and we need to regulate it. *The Correspondent*. Retrieved from *https://thecorrespondent.com/310/your-car-has-a-weight-problem-and-we-need-to-regulate-it/41009665950-d1c675d3*

Friedrich, B. (2015). *The effect of autonomous vehicles on traffic*. In M. Maurer, C. Gerdes, B. Lenz & H. Winner (Eds.), *Autonomous driving: Technical, legal and social aspects* (Chapter 16, pp. 317-334). Retrieved from *https://link.springer.com/book/10.1007/978-3-662-48847-8*

Friedrich, M. & Hartl, M. (2016). *Schlussbericht MEGAFON: Modellergebnisse geteilter autonomer Fahrzeugflotten des öffentlichen Nahverkehrs*. Retrieved from the University of Stuttgart website: *https://www.isv.uni-stuttgart.de/vuv/publikationen/downloads/MEGAFON_Abschlussbericht_V028_20161212.pdf*

Fundamentele relatie. (2020). Retrieved June 4, 2020, from Fandom: *https://verkeer.fandom.com/wiki/Fundamentele_relatie*

Gabriel12. (s.d.). *Paris, France- 2nd October, 2019: Busy mix of roadway traffic around place Saint Michel in Central Paris* [Stockfoto]. Shutterstock. Retrieved from *https://www.shutterstock.com/fr/image-photo/paris-france-2nd-october-2019-busy-1532785715*

Gavanas, N. (2019). Autonomous road vehicles: Challenges for urban planning in European Cities. *Urban science 3*(2), 61. Retrieved from *https://doi.org/10.3990/urbansci3020061*

Gemeinsam Lösungen finden. (2019, mei 8). *Austriatech*. Retrieved from *https://www.austriatech.at*

Geneva Convention on Road Traffic. September 19, 1949. Retrieved from *https://www.worlddriversassociation.com/pdf/CONVENTION%20ON%20ROAD%20TRAFFIC1949.pdf*

Germanchev, A., Eastwood, B. & Hore-Lacy, W. (2019). *Infrastructure changes to support automated vehicles on rural and metropolitan highways and freeways. Module 2: Road audit* (Austroads Technical Report No AP-T348-19). Retrieved from *https://austroads.com.au*

Gowling WLG. (2018, August 15). How will infrastructure need to change for connected and autonomous vehicles (CAVs)?. *Lexology*. Retrieved from *https://www.lexology.com*

Gowling WLG & UK Autodrive. (2018). *Paving the way: Building the road infrastructure for connected and autonomous vehicles*. Retrieved from *https://gowlingwlg.com/getmedia/af950092-954a-43ac-ad8f-b6df65734014/building-the-road-infrastructure-of-the-future.pdf.xml?ext=.pdf*

Hagenzieker, M.P., van der Kint, S., Vissers, L., Van Schagen, I.N.L.G., de Bruin, J., van Gent, P., Commandeur, J.J.F. (2020). Interactions between cyclists and automated vehicles: Results of a photo experiment. *Journal of transportation safety & security 12*(1), 94-115. Retrieved from *https://doi.org/10.1080/19439962.2019.1591556*

Hannon, E., Knupfer, S., Stern, S., Sumers, B. & Nijssen, J.T. (2019). *An integrated perspective on the future of mobility. Part 3: Setting the direction toward seamless mobility* (Sustainability & Resource Productivity Practice). Retrieved from the McKinsey & Company website: *https://www.mckinsey.com/~/media/mckinsey/business%20functions/sustainability/our%20insights/the%20road%20to%20seamless%20urban%20mobility/an-integrated-perspective-on-the-future-of-mobility-part-3-vf.ashx*

Harari, Y.N. (2018). *21 lessons for the 21st century*. London: Random House.

Heilig, M., Mallig, N., Schröder, O., Kagerbauer, M. & Vortisch, P. (2018). Implementation of free-floating and station-based carsharing in an agent-based travel demand model. *Travel behavior and society, 12*, 151-158. Retrieved from *https://doi.org/10.1016/j.tbs.2017.02.002*

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

Hill, A. (Ed.). (2019). Big ideas: What's the future of mobility going to look like? [Special edition]. *ITS International*, *25*(May/June). Retrieved from *http://digital.itsinternational.com/2019/global/may-jun/html5/index.html*

Hormann, J. & Bakker, S. (2019). *Stappenplan iVRI: Handreiking voor wegbeheerders*. Retrieved from the Kennisplatform CROW website: *https://www.crow.nl/downloads/pdf/verkeer-en-vervoer/verkeersmanagement/verkeersregelinstallaties/stappenplan-ivri*

How connectivity will make roads and cars safer in 2019. (2019, January 31). *Austriatech*. Retrieved from *https://www.austriatech.at*

Hughes, H. (2018, September 27). *Connected and autonomous vehicles (CAV): Implications for road authorities and TII* [presentation]. Dublin: Transport Infrastructure Ireland (TII). Retrieved from *https://www.tii.ie/tii-library/conferences_and_seminars/*

Huizenga, R. & Berge, Ø. (2019). Oslo-studie: De impact van autonome voertuigen op het vervoer in de stad. *NM magazine*, *14*(2), 28-29. Retrieved from *https://www.nm-magazine.nl*

I-DREAMS. (n.d.). Retrieved from *https://idreamsproject.eu/wp/*

Immers, B., Tampère, C. & Logghe, S. (2009). *10 verbeteropties op weg naar een performant en duurzaam transportsysteem voor België*. Retrieved from the Fédération belge et luxembourgeoise de l'automobile et du cycle. Retrieved from *http://www.febiac.be/documents_febiac/2009/etude-touring/master%20v05.pdf*

Inframix. (2017). *Infrastructure categorization: ISAD levels*. Retrieved from *https://www.inframix.eu/infrastructure-categorization/*

InterCor: Interoperable corridors deploying cooperative intelligent transport systems [brochure]. (2020, January). Retrieved from *https://intercor-project.eu/library/#*

International Association of Public Transport (UITP). (n.d.). *SPACE: The road to better mobility*. Retrieved from *https://space.uitp.org/*

International Transport Forum (ITF). (2015). *Urban mobility system upgrade: How shared self-driving cars could change city traffic* (ITF Corporate Partnership Board [CPB] Report). Retrieved from *https://www.itf-oecd.org/sites/default/files/docs/15cpb_self-drivingcars.pdf*

International Transport Forum (ITF). (2017). *Transition to shared mobility: How large cities can deliver inclusive transport services* (ITF Corporate Partnership Board [CPB] Report). Retrieved from *https://www.itf-oecd.org/sites/default/files/docs/transition-shared-mobility.pdf*

International Transport Forum (ITF). (2018). *Safer roads with automated vehicles?* (ITF Corporate Partnership Board [CPB] Report). Retrieved from *https://www.itf-oecd.org/safer-roads-automated-vehicles-0*

ISO/TC 22 on Road Vehicle. (2019, January 17). *Draft NWIP to be proposed by ISO/TC 241 on Road Traffic Safety (RTS): Ethical considerations for driverless vehicles* (No N 3842). Geneva, Switzerland: International organization for Standardization; La Plaine Saint-Denis, France: Association Française de Normalisation (AFNOR).

Johnson, C. (2017). *Readiness of the road network for connected and autonomous vehicles*. Retrieved from the Royal Automobile Club Foundation for Motoring (RAC Foundation). website: *https://www.racfoundation.org/wp-content/uploads/2017/11/CAS_Readiness_of_the_road_network_April_2017.pdf*

Kansen, M., van der Waard, J. & Savelberg, F. (2018). *Sturen in parkeren*. Retrieved from the Kennisinstituut voor Mobiliteitsbeleid (KiM) website: *https://www.kimnet.nl/publicaties/rapporten/2018/06/18/sturen-in-parkeren*

Kelechava, B. (2016, November 3). Defining self-driving cars and automated vehicle systems in SAE J 3016. *American National Standards Institute (ANSI)*. Retrieved from *https://blog.ansi.org*

Keolis. (n.d.). *Autonomous shuttles: Keolis, pioneer of the 100% electric, autonomous vehicle*. Retrieved from *https://www.keolis.com/en/our-services/transport-solutions/autonomous-shuttles*

Kerner, L. (2016, February). *Are we in a tech bubble?* [Presentation]. Retrieved from *https://www.slideshare.net/loukerner/bubble-cartoon*

Klochikhin, E. (2019, January 25). Autonomous vehicles and the hidden parking problem: Where will we park self-driving cars?. *Medium*. Retrieved from *https://medium.com/predict/autonomous-vehicles-and-the-hidden-parking-problem-where-will-we-park-self-driving-cars-e5f2ea1a1f0d*

KPMG International. (2018). *Autonomy delivers: An oncoming revolution in the movement of goods*. Retrieved from *https://advisory.kpmg.us/articles/2018/autonomy-delivers-an-oncoming-revolution-in-the-movement-of-goods.html*

KPMG International. (2019a). *KPMG 2019 autonomous vehicles readiness index: Assessing countries' preparedness for autonomous vehicles*. Retrieved from *https://assets.kpmg/content/dam/kpmg/xx/pdf/2019/02/2019-autonomous-vehicles-readiness-index.pdf*

KPMG International. (2019b). *KPMG's 20th consecutive global automotive executive survey 2019: Executive summary*. Retrieved from *https://automotive-institute.kpmg.de/GAES2019/downloads*

Krabbendam, V. (2019, January 17). Consortium kiest ITS-G5 voor communicatie truck platooning. *Zelfrijdendvervoer.nl*. Retrieved from *https://www.zelfrijdendvervoer.nl*

Kunert, M., Large, D., Burnett, G., Meijer, R., Paardekooper, J.-P., van Dam, E., ... & Cieslik, I. (2018). *PROSPECT: Proactive safety for pedestrians and cyclists. Deliverable D5.1: VRU motion and intent modelling, situation analysis and collision risk estimation*. Retrieved from the CORDIS EU Research Results, European Commission (EC) website: *https://cordis.europa.eu/project/id/634149/results*

Leeb, R. (Ed.). (2019). Mobilität 2050: Verkerhsinfrastruktur 4.0 = Mobilité 2050: Infrastructure de transport 4.0 [special issue]. *Strasse und Verkehr = Route et trafic, 105*(1-2). Retrieved from *http://www.vss.ch/metanavigation/download/*

Liao, F., Molin, E., Timmermans, H. & van Wee, B. (2020). Carsharing: The impact of system characteristics on its potential to replace private car trips and reduce car ownership. *Transportation, 47*(2), 935-970.

Lindström, A., Van den Berghe, W., Maes, J., Machata, K., Eenink, R., Linder, Astrid, ... Fric, J. (2018). *Safety through automation?: Ensuring that automated and connected driving contribute to a safer transportation system* [Position paper]. Retrieved from the Forum of European Road Safety Research Institutes (FERSI) website: *https://fersi.org/wp-content/uploads/2019/02/180202-Safety-through-automation-final.pdf*

Litzler, J-B. (2019, July 15). Déçue par sa navette autonome, La Défense arrête l'expérience. *Le figaro*. Retrieved from *https://immobilier.lefigaro.fr/article/decue-par-sa-navette-autonome-la-defense-arrete-l-experience_21ebcd88-a4d5-11e9-a13f-3957458a90bd/*

Lohmann, R. (n.d.). Rivium business park first to introduce autonomous shuttles in mixed traffic. *2getthere*. Retrieved from *https://www.2getthere.eu*

Lombardo, J. (2018, January 17). How will autonomous vehicles impact how we build roads?. *ForConstructionPros.com*. Retrieved from *https://www.forconstructionpros.com*

Lytrivis, P., Papanikolaou, E., Amditis, A., Dirnwöber, M., Froetscher, A., Protzmann, R., … Kerschbaumer, A. (2018, April). Advances in road infrastructure, both physical and digital, for mixed vehicle traffic flows. In *Solutions for society, economy and environment*. Proceedings of the 7th transport research arena (TRA 2018), Vienna, Austria.

Mannion, P. (2019, February 10). *Vulnerable road user detection: State-of-the-art and open challenges*. Retrieved from the arXiv, Cornell University website: *https://arxiv.org/pdf/1902.03601.pdf*

Marchesini, P. & Weijermars, W. (2010). *The relationship between road safety and congestion on motorways: A literature review of potential effects* (SWOV Report No R-2010-12). Retrieved from the Institute for Road Safety Research (SWOV) website: *https://www.swov.nl*

Marks, J. (2018a, June 5). How to ensure the safety of self-driving cars: Part 1/5. *Medium*. Retrieved from *https://medium.com/@olley_io/how-to-ensure-the-safety-of-self-driving-cars-part-1-5-2fcc891ea90b*

Marks, J. (2018b, June 5). How to ensure the safety of self-driving cars: Part 2/5. *Medium*. Retrieved from *https://medium.com/@olley_io/how-to-ensure-the-safety-of-self-driving-cars-part-2-5-b4eafb067534*

Marks, J. (2018c, June 5). How to ensure the safety of self-driving cars: Part 3/5. *Medium*. Retrieved from *https://medium.com/@olley_io/how-to-ensure-the-safety-of-self-driving-cars-part-3-5-73157e8de29c*

Marks, J. (2018d, June 5). How to ensure the safety of self-driving cars: Part 4/5. *Medium*. Retrieved from *https://medium.com/@olley_io/how-to-ensure-the-safety-of-self-driving-cars-part-4-5-66ce9f24fce5*

Marks, J. (2018e, June 5). How to ensure the safety of self-driving cars: Part 5/5. *Medium*. Retrieved from *https://medium.com/@olley_io/how-to-ensure-the-safety-of-self-driving-cars-part-5-5-1ec043d67e4f*

Martens, M. (2014, September 11). Mens en auto moeten leren samenwerken. *VerkeersNet*. Retrieved from *https://www.verkeersnet.nl*

Martinez, L. & Viegas, J. (2016, January 10-14). *Concepts and impacts of new urban shared mobility alternatives: An agent-based simulation model for the city of Lisbon, Portugal*. Presentation for the 95th annual meeting of the Transportation Research Board, Washington, D.C., USA. Retrieved from *https://www.itf-oecd.org/concepts-and-impacts-new-urban-shared-mobility-alternatives*

McKinsey & Company. (n.d.). *What steps must cities take to realize the full benefits of autonomous vehicles?*. Retrieved from *https://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/a-new-look-at-autonomous-vehicle-infrastructure#*

McKinsey & Company. (2016). *Automotive revolution: Perspective towards 2030: How the convergence of disruptive technology-driven trends could transform the auto industry*. Retrieved from *https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/disruptive-trends-that-will-transform-the-auto-industry*

McNulty, J. (2019, January 31). Mean streets: Self-driving cars will «cruise» to avoid paying to park. *ScienceDaily*. Retrieved from *https://www.sciencedaily.com*

Mearian, L. (2016, December 8). New Audis can now talk to traffic lights. *Computerworld*. Retrieved from *https://www.computerworld.com*

Metamorworks. (n.d.). *Cockpit van autonome auto: Een voertuig met zelfrijdende modus en een vrouw bestuurder ontspannen* [Stockfoto]. Shutterstock. Retrieved from *https://www.shutterstock.com/nl/image-photo/cockpit-autonomous-car-vehicle-running-self-631212983*

Ministerie van de Vlaamse Gemeenschap (MVG), Administratie Wegen en Verkeer (AWV) & Opzoekingscentrum voor de Wegenbouw (OCW). (2001). *Catalogus schade aan wegverhardingen*. Retrieved from *https://wegenenverkeer.be/sites/default/files/uploads/documenten/Schadecatalogus_0.pdf*

Ministerie van de Vlaamse Gemeenschap (MVG), Agentschap Wegen en Verkeer (AWV), Afdeling Expertise Verkeer en Telematica, Team Veiligheid en Ontwerp. (2018). *Vademecum weginfrastructuur (VWI). Deel autosnelwegen*. Retrieved from *https://wegenenverkeer.be/zakelijk/documenten/ontwerprichtlijnen/autosnelwegen*

Ministry of Land, Infrastructure, Transport and Tourism (MLIT). (n.d.). *«Michi-no-Eki» rest areas*. Retrieved from *https://www.mlit.go.jp/road/road_e/q7_restareas.html*

Morlion, P. (2018, January 6). Met de zelfrijdende auto krijgen onze mobiliteitsministers een historische kans op een visionair beleid [Opinion]. *Knack*. Retrieved from *https://www.knack.be*

Morsink, P., Klem, E., Wilmink, I. & de Kievit, M. (2016). *Zelfrijdende auto's: Ontwikkelagenda ZRA en wegontwerp* (version 03, final). Retrieved from the Kennisplatform CROW website: *https://www.crow.nl/downloads/pdf/verkeer-en-vervoer/wegontwerp/zelfrijdende-autos-verkenning-van-implicaties-op-h.aspx?ext=.pdf*

Mouyal, N. (2018, February 15). Harvesting energy from roads: New technologies capture ambient energy and convert it to electric power. *IEC e-tech*. Retrieved from *https://etech.iec.ch*

Nasir, M.K., Noor, R.M., Kalam, M.A. & Masum, B.M. (2014). Reduction of fuel consumption and exhaust pollutant using intelligent transport systems. *The scientific world journal*, 836375. Retrieved from *http://dx.doi.org/10.1155/2014/836375*

National Association of City Transportation Officials (NACTO). (2017). *Blueprint for autonomous urbanism. Module 1: Designing cities edition*. Retrieved from *https://cdn.atlantaregional.org/wp-content/uploads/blueprint-for-autonomous-urbanism.pdf*

National Association of City Transportation Officials (NACTO). (2019). *Blueprint for autonomous urbanism* (Second edition). Retrieved from *https://nacto.org/publication/bau2/*

La navette autonome, à la conquête de La Défense. (2017, September 25). *Wavestone transportshaker*. Retrieved from *https://www.transportshaker-wavestone.com*

Nesnow, G. (2018, February 9). 73 mind-blowing implications of driverless cars and trucks. *Medium*. Retrieved from *https://medium.com/@DonotInnovate/73-mind-blowing-implications-of-a-driverless-future-58d23d1f338d*

O'Brian, C. (2019, July 29). The drive to dominate autonomous shuttles. *The innovator*. Retrieved from *https://innovator.news*

Ohern, M. (2016, May 25). Platooning and dedicated truck lanes. *Jefferson policy journal*. Retrieved from *https://jeffersonpolicyjournal.com/*

Oster, C. (n.d.). *The nexus of AVs, bikes, and pedestrians: Similar problems, similar solutions*. Presentation for the University of Delaware, Joseph R. Biden, Jr. School of Public Policy & Administration, Newark, DE, USA. Retrieved from *https://ecf.com/sites/ecf.com/files/Oster.C_The_nexus_of_AVs_bikes_and_pedestrians.pdf*

Over tien jaar hebben we de zelfrijdende auto onder controle. (2018, December 24). *De Tijd*. Retrieved from *https://www.tijd.be*

Papanikolaou, E. (Ed.). (2018). *INFRAMIX: Road infrastructure ready for mixed vehicle traffic Flows. Deliverable D.2.1: Requirements catalogue from the status quo analysis* (version 6.0). Retrieved from the INFRAMIX website: *https://inframix.eu/*

Parkin, J., Crawford, F., Flower, J., Alford, C. & Parkhurst, G. (n.d.). *Interactions of autonomous vehicles and cyclists: Results from real-world and simulator trials*. Presentation for the University of the West of England (UWE Bristol), Centre for Transport & Society, Bristol, UK. Retrieved from *https://ecf.com/sites/ecf.com/files/Parkin.J_Interactions_of_autonomous_vehicles_and_cyclists.pdf*

Parliament approves EU rules requiring life-saving technologies in vehicles. (2019, April 16). *News European Parliament*. Retrieved from *https://www.europarl.europa.eu/news/en/press-room/20190410IPR37528/parliament-approves-eu-rules-requiring-life-saving-technologies-in-vehicles*

Paulsen, J.T. (2018). *Physical infrastructure needs for autonomous & connected trucks: An exploratory study* (Master thesis, Norwegian University of Science and Technology [NTNU], Trondheim, Norway). Retrieved from *https://ntnuopen.ntnu.no/ntnu-xmlui/bitstream/handle/11250/2562799/19642_FULLTEXT.pdf?sequence=1*

Perkins Coie & Association for Unmanned Vehicle Systems International (AUVSI). (2019). *2019 autonomous vehicles survey report*. Retrieved from *https://www.perkinscoie.com*

Pizzuto, L., Thomas, C., Wang, A. & Wu, T. (2019, January 25). How China will help fuel the revolution in autonomous vehicles. *McKinsey & Company*. Retrieved from *https://www.mckinsey.com*

Puylaert, G. (2019, May 9). Waarom wetgeving voor autonoom vervoer Europees geregeld moet worden. *Biind*. Retrieved from *https://www.biind.nl*

Quelle stratégie pour une réponse adéquate aux besoins?: À Londres: Des bornes de rechargement dans les réverbères. (2019). *La CeMathèque*, (49), 23. Retrieved from *http://mobilite.wallonie.be/home/centre-de-documentation/cematheque.html*

Raposo, A. & Ciuffo, B. (Eds.). (2019). *The future of road transport: Implications of automated, connected, low-carbon and shared mobility*. Retrieved from the EU Science Hub, European Commission (EC) website: *https://ec.europa.eu/jrc/en/facts4eufuture/future-of-road-transport*

Redactie Automobiel Management. (2019a, February 26). Autonome auto maakt de stad leefbaarder. *Automobiel Management (AM)*. Retrieved from *https://www.automobielmanagement.nl*

Redactie Automobiel Management. (2019b, March 4). Duitse auto-industrie investeert €60 miljard in EV en zelfrijdende auto. *Automobiel Management (AM)*. Retrieved from *https://www.automobielmanagement.nl*

Redactie Automobiel Management. (2019c, March 11). PSA: Geen niveau 4 en 5 autonome voertuigen voor particulier. *Automobiel Management (AM)*. Retrieved from *https://www.automobielmanagement.nl*

Redactie Automobiel Management. (2019d, April 15). De autonome auto is nog ver weg. *Automobiel Management (AM)*. Retrieved from *https://www.automobielmanagement.nl*

Redactie e-Drivers. (2019, October 31). Inductie laden van uw elektrische auto. *E-drivers.com (ED)*. Retrieved from *https://e-drivers.com/inductie-laden-van-uw-elektrische-auto/*

Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing. Directive 95/46/EC (General Data Protection Regulation). (2016). *Official journal of the European Union*, L 119, 1-88. Retrieved from *https://eur-lex.europa.eu/homepage.html*

Regulation (EU) 2019/881 of the European Parliament and of the Council of 17 April 2019 on ENISA (the European Union Agency for Cybersecurity) and on information and communications technology cybersecurity certification and repealing. Regulation (EU) No 526/2013 (Cybersecurity Act). (2019). *Official journal of the European Union*, L 151, 15-69. Retrieved from *https://eur-lex.europa.eu/homepage.html*

Regulation (EU) 2019/2144 of the European Parliament and of the Council of 27 November 2019 on type-approval requirements for motor vehicles and their trailers, and systems, components and separate technical units intended for such vehicles, as regards their general safety and the protection of vehicle occupants and vulnerable road users, amending. Regulation (EU) 2018/858 of the European Parliament and of the Council and repealing Regulations (EC) No 78/2009, (EC) No 79/2009 and (EC) No 661/2009 of the European Parliament and of the Council and Commission Regulations (EC) No 631/2009, (EU) No 406/2010, (EU) No 672/2010, (EU) No 1003/2010, (EU) No 1005/2010, (EU) No 1008/2010, (EU) No 1009/2010, (EU) No 19/2011, (EU) No 109/2011, (EU) No 458/2011, (EU) No 65/2012, (EU) No 130/2012, (EU) No 347/2012, (EU) No 351/2012, (EU) No 1230/2012 and (EU) 2015/166. (2019). *Official journal of the European Union*, L325, 1-40. Retrieved from *https://eur-lex.europa.eu/homepage.html*

Regulation No 79 of the Economic Commission for Europe of the United Nations (UN/ECE): Uniform provisions concerning the approval of vehicles with regard to steering equipment. (Addendum 78: Regulation No 79, revision 2). (2008). *Official journal of the European Union*, L137, 25-51. Retrieved from *https://eur-lex.europa.eu/homepage.html*

Ricker, L. & Akdemir, S. (2020, February). *Autonomous shuttle @STIB*. Presentation for the ITS-workshop autonomous shuttles, Brussels, Belgium. Retrieved from *http://www.its.be/sites/default/files/STIB.pdf*

Robinson, T.L., Wallbank, C. & Baig, A. (2017). *Automated driving systems: Understanding future collision patterns: Development of methodology and proof of concept*. (TRL Published Project Report [PPR] No 851). Retrieved from the Transportation Research Laboratory (TRL) website: *https://trl.co.uk*

Rombaut, E., Feys, M. Vanobberghen, W., De Cauwer, C. & Vanhaverbeke, L. (2020, November). *Experience and acceptance of an autonomous shuttle in the Brussels Capital Region* [Paper submitted for publication]. IEEE Forum on integrated and sustainable transportation system (ISTS 2020), Delft, The Netherlands.

Rosevear, J. (2018, September 6). Self-driving cars: Understanding the 6 autonomous levels. *The motley fool*. Retrieved from *https://www.fool.com*

Ruiz, D. (2019, May 17). Why language matters in the self-driving revolution [Blog post]. Retrieved from *https://blogs.terrapinn.com/highwaysuk/daniel-ruiz-chief-executive-zenzic/*

SAE International releases updated visual chart for its "levels of driving automation" standard for self-driving vehicles. (2018, December 11). *SAE International*. Retrieved from *https://www.sae.org/*

Sanderson, N. (2019, August 28). Canada's micro-mobility era is off with a bang, as provinces strive to regulate demand, safety. *Electric autonomy Canada*. Retrieved from *https://electricautonomy.ca*

Self-driving cars in the EU: From science fiction to reality. (2019, January 14). *News European Parliament*. Retrieved from *https://www.europarl.europa.eu/news/en/headlines/economy/20190110STO23102/self-driving-cars-in-the-eu-from-science-fiction-to-reality*

Service public fédéral Mobilité et Transports (SPF Mobilité et Transports). (2016). Accord de coopération de 15 juillet 2014 relatif à la Directive 2010/40/UE du Parlement européen et du Conseil du 7 juillet 2010 concernant le cadre pour le déploiement de systèmes de transport intelligents dans le domaine du transport routier et d'interfaces avec d'autres modes de transports. *Moniteur belge*, 12.08.2016 (Ed. 2), C – 2016/14240, 52061-52063. Retrieved from *http://www.ejustice.just.fgov.be/cgi/welcome.pl*

Smolnicki, P.M. (2017, October). *Connected & automated urban mobility, zombie cars and kitchen knives: Will autonomous automobiles, self-driving car-sharing and ride-hailing, and driverless shuttles harm cities?*. Paper for the 53rd ISOCARP/OAPA congress on smart communities, Portland, OR, USA. Retrieved from *https://pdfs.semanticscholar.org/f524/d5271557269a0d565c742db0d47eaabaf77d.pdf*

Society of Motor Manufacturers and Traders (SMMT). (2017). *Connected and autonomous vehicles* [SMMT position paper]. Retrieved from *https://www.smmt.co.uk/wp-content/uploads/sites/2/SMMT-CAV-position-paper-final.pdf*

Somers, A. (2019a). *Infrastructure changes to support automated vehicles on rural and metropolitan highways and freeways. Module 1: Audit specification* (Austroads Technical Report No AP-T347-19). Retrieved from *https://austroads.com.au*

Somers, A. (2019b). *Infrastructure changes to support automated vehicles on rural and metropolitan highways and freeways. Module 3: Asset standards* (Austroads Research Report No AP-R604-19). Retrieved from *https://austroads.com.au*

Somers, A. (2019c). *Infrastructure changes to support automated vehicles on rural and metropolitan highways and freeways. Module 4: Emerging asset information technology* (Austroads Research Report No AP-R605-19). Retrieved from *https://austroads.com.au*

Somers, A. (2019d). *Infrastructure changes to support automated vehicles on rural and metropolitan highways and freeways. Module 5: Project findings and recommendations* (Austroads Research Report No AP-R606-19). Retrieved from *https://austroads.com.au/*

Sortie du thermique (véhicules diesel et essence). (2020, May 26). *Bruxelles environnement*. Retrieved from *https://environnement.brussels/*

Soteropoulos, A., Berger, M. & Ciari, F. (2019). Impacts of automated vehicles on travel behaviour and land use: An international review of modelling studies. *Transport reviews*, 39(1), 29-49. Retrieved from *https://doi.org/10.1080/01441647.2018.1523253*

Specifieke parkeerplaatsen voor deelsteps in de maak. (2019, November 19). *Bruzz*. Retrieved from *https://www.bruzz.be/mobiliteit/specifieke-parkeerplaatsen-voor-deelsteps-de-maak-2019-11-19*

Stam, K. (2020, February). *Autonomous shuttle project* [Presentation]. Retrieved from *http://www.its.be/sites/default/files/maria%20middelares.pdf*

TED. (2015, June 26). Chris Urmson: *How a driverless car sees the road* [Video]. Retrieved from YouTube. *https://www.youtube.com/watch?v=tiwVMrTLUWg*

Thibault, M., Böhm, M., Ollinger, E., Hedhli, A., Patey, I, Wedlock, M., ... Botha, R. (2019). *Connected vehicles: Challenges and opportunities for road operators* (PIARC Report No 2019R11EN). Retrieved from *https://www.piarc.org/en*

Tillema, T., Gelauff, G., van der Waard, J., Berveling, J. & Moorman S. (2017). *Paden naar een zelfrijdende toekomst: Vijf transitiestappen in beeld* (KiM No 17-A04). Retrieved from the Kennisinstituut voor Mobiliteitsbeleid (KiM) website: *https://www.kimnet.nl/publicaties/presentaties/2017/07/01/paden-naar-een-zelfrijdende-toekomst*

Transport & Environment (TE). (2019, September). *Low-emission zones are a success: But they must now move to zero-emission mobility* [Briefing]. Retrieved from *https://www.transportenvironment.org*

Transport Systems Catapult. (2017). *Future proofing infrastructure for connected and automated vehicles* (Transport Systems Catapult Technical Report, V1.1). Retrieved from *https://s3-eu-west-1.amazonaws.com/media.ts.catapult/wp-content/uploads/2017/04/25115313/ATS40-Future-Proofing-Infrastructure-for-CAVs.pdf*

Transportation for America (T4America). (2018). *Parking & street design: Shared active transportation playbook*. Retrieved from *https://playbook.t4america.org/parking-street-design/*

Treat, J.R., Tumbas, N.S., McDonald, S.T., Shinar, D., Hume, R.D., Mayer, R.E., ... Castellan, N.J. (1979). *Tri-level study of the causes of traffic accidents: Executive summary* (No DOT HS-805 099). Washington: US Department of Transportation (DOT), National Highway Traffic Safety Administration (NHTSA).

Uber haalt Jump-fietsen weg uit verschilllende Brusselse gemeenten wegens vandalisme. (2019, September 5). *Knack*. Retrieved from *https://datanews.knack.be/ict*

Upton, N. (2017, January 5). Connecting the connected car: What needs to happen now [Blog post]. *TechTarget*. Retrieved from *https://internetofthingsagenda.techtarget.com*

US Department of Transportation (DOT). (n.d.). *Connected vehicles: Vehicle-to-pedestrian communications* (No FHWA-JPO-15-242). Retrieved from *https://www.its.dot.gov/factsheets/pdf/CV_V2Pcomms.pdf*

US Department of Transportation (DOT). (2018). *Preparing for the future of transportation: Automated vehicles 3.0*. Retrieved from *https://www.transportation.gov/av/3/preparing-future-transportation-automated-vehicles-3*

Ush. (2020, February). *From pilot phase to market deployment: Current bottlenecks*. Presentation for the ITS event @Solvay, Brussels, Belgium. Retrieved from *http://www.its.be/sites/default/files/Ush_ITS%20event%2012-02.pdf*

van de Weijer, B. (2019, October 10). Binnenkort op de weg: Zelfrijdende robottaxi's zonder reservemens achter het stuur. *De Volkskrant*. Retrieved from *https://www.volkskrant.nl*

Van Den Bergh, J. (2013, July 17). *Projet de loi portant création du cadre pour le déploiement de systèmes de transport intelligents et modifiant la loi du 10 avril 1990 réglementant la sécurité privée et particulière* (Chambre des représentants de Belgique: Rapport fait au nom de la Commission de l'Infrastructure, des Communications et des Entreprises publiques No 53 2943/002). Retrieved from *https://www.dekamer.be/kvvcr/index.cfm?language=fr*

van der Walle, E. (ed.). (2017). *InterCor: Plan of action* TESTFEST ITS-G5, Dordrecht, July 3-6, 2017. Retrieved from the InterCor website: *https://intercor-project.eu/wp-content/uploads/sites/15/2017/06/Plan-of-Action-Testfest-ITS-G5_v-1.0-Participants.pdf*

Van Geem, C., Massart, T., Van Buylaere, A., Draps, M., Laforce, M. & Hindrijckx, M. (2020). *Inspection visuelle & gestion de réseaux routiers (villes et communes): Catalogue des dégradations* (Méthode de mesure CRR No MF89, Rev. 1). Brussels: Belgian Road Research Centre (BRRC).

van Nes, C.N. & Duivenvoorden, C.W.A.E. (2017). *Veilig naar het verkeer van de toekomst: Nieuwe mogelijkheden, risico's en onderzoeksagenda voor de verkeersveiligheid bij automatisering van het verkeerssysteem* (SWOV Rapport No R-2017-2). Retrieved from *https://www.swov.nl*

Van Schagen, I., van der Kint, S. & Hagenzieker, M. (2017). *Zelfrijdende voertuigen: Wat betekent dat voor fietsers en voetgangers?* (SWOV Rapport No R-2017-22). Retrieved from *https://www.swov.nl*

Van Wijngaarden, M. (2019a, May 23). *Ford zet robot in voor pakketbezorging met AV*. Automobiel Management (AM). Retrieved from *https://www.automobielmanagement.nl*

Van Wijngaarden, M. (2019b, May 30). Robottaxi wordt niet snel winstgevend. *Automobiel Management (AM)*. Retrieved from *https://www.automobielmanagement.nl*

Vanaf 2021 zelfrijdende busjes in Antwerpen. (2018, October 10). *Het Laatste Nieuws (HLN)*. Retrieved from *https://www.hln.be*

Véhicules autonomes: Navya victime du retard au décollage. (2019, July 25). *Le Point*. Retrieved from *https://www.lepoint.fr*

Vellinga, N.E. & Vellinga, W.H. (2015). Enkele verkeersrechtelijke aspecten van toelating van (deels) zelfrijdende of autonome auto's tot het wegverkeer. *Verkeersrecht*, (3), 82-90. Retrieved from *https://www.crow.nl/downloads/pdf/portals/dutch-roads/artikel-autonome-voertuigen-uit-verkeersrecht.aspx?ext=.pdf*

Venezia, M. (2015, December 16). What is the difference between GNSS and GPS? [Blog post]. Retrieved from *https://www.semiconductorstore.com/blog/2015/What-is-the-Difference-Between-GNSS-and-GPS/1550/*

Vermaat, P., Reed, N., de Kievit, M., Wilmink, I., Zlocki, A. & Shladover, S.E. (2017). *DRAGON: Driving automated vehicle growth on national roads. Deliverable 4.1: WP4, findings report* (version 1.0). Retrieved from *https://www.cedr.eu*

Verrips, A., Hoen, A. et al. (2016). *Kansrijk mobiliteitsbeleid*. Retrieved from the Planbureau voor de Leefomgeving (PBL) website: *https://www.pbl.nl/publicaties/kansrijk-mobiliteitsbeleid*

VIAS Institute. (2018, October 4). *Test with self-driving shuttle at the Lion's Mound, Waterloo* [Photo].

VIAS Institute & Federal Public Service Mobility and Transport. (2018, September 4). *Driverless shuttle bus drives for the first time on public roads in Belgium* [Press release]. Retrieved from *https://www.vias.be/en/newsroom/shuttle-bus-drives-for-the-first-time-on-public-roads-in-belgium-/*

Virginia Department of Transportation (VDOT). (2017). *Connected and automated vehicle program plan*. Richmond, Virginia, USA: Auteur. Retrieved from *https://www.virginiadot.org*

Visnic, B. (2019, April 2). European Union approves mandatory vehicle speed-limiting feature. *SAE International*. Retrieved from *https://www.sae.org*

Vlaamse Minister van Mobiliteit, Openbare Werken, Vlaamse Rand, Toerisme en Dierenwelzijn, Vlaamse Minister van Werk, Economie, Innovatie en Sport. 2018). *Bisconceptnota aan de regering betreffende geconnecteerde en geautomatiseerde mobiliteit in Vlaanderen* (No VR 2018 0203 DOC.0194/1BIS). Retrieved from *https://www.ewi-vlaanderen.be/sites/default/files/conceptnota_-_geconnecteerde_en_geautomatiseerde_mobiliteit_in_vlaanderen.pdf*

Vlaamse Overheid, Departement Mobiliteit en Openbare Werken. (n.d.). *Basisbereikbaarheid*. Retrieved from *https://www.vlaanderen.be/basisbereikbaarheid*

VMS/Insight. (2019). *Het effect van ADAS op schadeherstel, onderhoud en reparatie: Highlights ADAS-onderzoek*. Retrieved from *https://www.bovag.nl/getattachment/Pers/Persberichten/Bijna-een-kwart-minder-schade-door-ADAS/ADAS2019_highlights_def_e_los.pdf.aspx?lang=nl-NL*

Voronov, A., Hultén, J., Wedlin, J. & Englund, C. (2016). *Radar reflecting pavement markers for vehicle automation*. Retrieved from *https://www.ri.se/en/what-we-do/projects/radar-reflecting-pavement-markers-vehicle-automation*

Vrije Universiteit Brussel (VUB). (2019). *Test self-driving shuttle on Brussels Health Campus* [Photo]

Waarom Rotterdam zijn lage-emissiezone afbouwt. (2019, December 27). *Bruzz*. Retrieved from *https://www.bruzz.be*

Wang, M., van Maarseveen, S., Happee, R., Tool, O. & van Arem, B. (2019). Benefits and risks of truck platooning on freeway operations near entrance ramp. *Transportation research record (TRR), 2673*(8), 588-602. Retrieved from *https://doi.org/10.1177/0361198119842821*

Wenen schort experiment met zelfrijdende minibus op na ongeval. (2019, July 19). *Het Laatste Nieuws (HLN)*. Retrieved from *https://www.hln.be*

What are the risks of allowing direct access to car data? (n.d.). Retrieved from *https://www.cardatafacts.eu/risk-direct-access-car-data/*

Wilmink, I., Calvert, S., de Kievit, M., Landen, T. & Zlocki, A. (2017). *DRAGON: Driving automated vehicle growth on national roads. Deliverable 2.1: WP2, exploration of impacts, constraints and enablers of automated vehicles on NRAs* (version 2). Retrieved from the Conference of European Directors of Roads (CEDR) website: *https://www.cedr.eu*

Woolsgrove, C. (2019). *Opportunities and threats of autonomous vehicles to other modes in urban areas*. Presentation for the European Cyclists' Federation (ECF), Dublin. Retrieved from *https://ecf.com/sites/ecf.com/files/Woolsgrove.C_opportunities_and_threats_of_autonomous_vehicles_to_other_modes_in_urban_areas.pdf*

Yoshida, H. (n.d.). *Automated driving service based at «Michi-no-eki» in rural mountainous areas* [Presentation]. Retrieved from *https://www.sip-adus.go.jp/evt/workshop2017/file/evt_ws2017_s5_HidenoriYoshida.pdf*

Zelfrijdende auto niet langer sneeuwblind. (2020, March 2). *De ingenieur*. Retrieved from *https://www.deingenieur.nl*

Zenzic. (2019). *UK connected and automated mobility roadmap to 2030*. Retrieved from *https://zenzic.io/roadmap/*

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Self-driving vehicles would be a solution to many traffic and transport-related problems that are pressing today. Or not? When and under what conditions would all these promises be kept? BRRC and representatives of road authorities, the automobile sector, public transport companies, research institutes, etc. are attempting to outline the state of affairs in this rapidly evolving matter. In particular, to get a picture of how infrastructure could or should evolve so that it does not inhibit the future deployment of self-driving vehicles, but rather contributes to their successful introduction.

For the time being, however, the human road user remains the starting point in the design and construction of road infrastructure, with that road user increasingly being supported by technological developments. In order for this support to function optimally, major infrastructural adjustments do not seem immediately necessary. Recognisable and harmonised signage (*possibly communication technology ready*) and sustainable and qualitative road surfaces seem to be the most important needs of the developers of self-driving vehicles at the moment.

Self-driving vehicles are becoming safer, more environmentally friendly, more efficient, more accessible, etc. For some, they also become more pleasant to use. More than just a new way of moving around, self-driving vehicles can play a role in the mobility of the future. (Shared) (rides with) self-driving vehicles can be an addition to public transport. Testing with shuttles that today operate over a limited fixed route, usually outside the public domain, may evolve into flexible *on-demand* services in the future. Depending on the role of self-driving vehicles in the transport system of the future, the importance of certain infrastructural facilities (*drop-off & pick-up* zones, car parks with additional facilities, etc.) will change. Much depends on the choices made for that future transport system. The text outlines a number of possible evolutions, especially for the urban environment.

In this report, we explore the future, and discuss possibilities for responding to it. The report provides insight into '***no regret***' measures in the field of road infrastructure. In addition, we sketch **the bigger picture**: road infrastructure is an essential condition for transport, but obviously has close interfaces with other aspects of society and the transport system in particular.

Probably the future will look different to some extent after all. Within 10 years, there may be opportunities that we can't even dream of today. However, the gradual deployment of self-driving vehicles forces us to think about the future we want and how the undoubtedly still necessary transport will happen. The introduction of self-driving vehicles offers the opportunity to shape that future rather than undergo it.

ITRD keywords

0132 – FORECAST ; 0698 – JOURNEY ; 1055 – TRANSPORT INFRASTRUCTURE ; 1145 – TRANSPORT MODE ; 1244 – AUTONOMOUS VEHICLE ; 8588 – STATE OF THE ART REPORT ; 8735 – INTELLIGENT TRANSPORT SYSTEM ; 9105 – MOBILITY (PERS)