Whitepaper

Future proof road infrastructure

An exploration of the impact of automated traffic and transportation

CROW-KpVV

CROW-KpVV develops, disseminates, and safeguards collective knowledge for decentralized authorities in the field of mobility. This knowledge fundamentally supports policy development and implementation.

About CROW

CROW devises smart and practical solutions for infrastructure, public space, traffic, and transportation issues in the Netherlands. We do this in collaboration with external professionals who share and apply knowledge for practical use. CROW is an independent non-profit knowledge organization that invests in knowledge for the present and future. We strive for the best solutions for issues ranging from policy to management in infrastructure, public space, traffic, transportation, work, and safety. Additionally, we are experts in procurement and contracting.

About Smart Mobility Collaboration

Governments collaborate within the Smart Mobility Collaboration to achieve greater impact and prevent duplications.

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Foreword

This whitepaper is a glimpse into the future, exploring possible visions of where we, as governments, road authorities, market players, and society, want to move towards in the dynamic world of mobility and technology. A significant development in this regard is the rise of automated vehicles (AVs), which we will increasingly witness in the traffic landscape in the coming years. Various studies in recent years have shown that AVs can contribute to sustainable, safe, and inclusive mobility and improve the quality of the living environment, vital societal challenges for the coming decades. However, there are also risks that the promises may not be fulfilled, leading to increased congestion or safety concerns. Therefore, a responsible introduction of automated transport into the current and future traffic system requires a gradual and well-considered approach. Various parties play a role in this process, including vehicle developers, ICT and transport companies, driving instructors, legislators, approval authorities, knowledge institutions, universities, and road authorities. Each plays a role based on their own perspective and, most importantly, through collaboration and coordination with each other.

Technological advancements offer opportunities to rethink the use of public space and redesign our living and traffic environments. Digitalization provides chances to make smarter use of space and "declutter" the physical environment, thereby improving the quality of the living environment. An exciting prospect. Physical infrastructure will be complemented by digital infrastructure, utilizing accurate maps in navigation systems, advanced communication and positioning technology, and an increasing amount of data to better manage and automate traffic. Physical and digital infrastructures will find a new balance through "essential physical road design features" and "essential digital characteristics," available data, and supporting technology. With these developments, we can expect to reap the benefits of automated traffic and transportation where societal and economic value is highest. But the question is, when will that happen?

This paper does not provide a comprehensive answer to this question. However, we do present several visions and development trajectories to make the physical infrastructure (road design) future-proof while maximizing the opportunities of digitalization. It is not realistic to expect a complete and sudden transformation, and fortunately, it is not necessary either. The basic principles of sustainable and safe road design, which we have been using since the end of the last century, already form a robust foundation. The necessary addition is to shift our focus not only through the lens of the "human road user" but increasingly through the lens of the "smart vehicle" that supports humans and can autonomously perform more driving tasks. This involves considerations regarding the utility and necessity of physical design elements, such as speed control, when the same can be achieved through technology in the vehicle. Traffic environment designers will increasingly adopt this perspective in the coming decades.

The authors of this paper do not allow themselves to be hindered by the current limitations of technology and regulations when presenting their visions. It is not the intention to predict the future either. We look at where we think we will be with our current knowledge and then reason backward to the present. The authors do not assume that everyone will share these visions. The goal is to stimulate and nourish discussions from various perspectives.

We hope that this paper achieves this objective and that you, as the reader, can use these visions as inspiration for further policy development in automated transport with an emphasis on road infrastructure.

From the perspective of CROW-KpVV, this project is somewhat exceptional. After all, the program does not typically project uncertain futures onto the current policy development of decentralized authorities. Nevertheless, there are times when it is necessary to dare to look further into the future, even if it does not always lead directly to actionable insights for tomorrow. This whitepaper is our attempt to do just that. Enjoy reading.

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Director, CROW-KpVV

The authors

Gerard van Dijck

With 24 years of experience in the field of traffic and transportation, as an entrepreneur, civil servant, and currently as Knowledge Manager Smart Mobility at CROW, Gerard is an experienced professional in his field. His expertise lies in strategic/tactical policy related to traffic management and Smart Mobility, and he possesses specialized knowledge of traffic control systems, behavior, regulations, transportation, driving skills aspects, etc. Gerard is also active in NEN, LVMB, CEN, and European projects.

Peter Morsink

Peter Morsink is a Strategic Advisor in Smart Mobility and Traffic Safety at Royal HaskoningDHV. As a project manager and expert, he works on various (inter) national projects and initiatives aimed at the safe and efficient integration of automated vehicles and ADAS (Advanced Driver Assistance Systems) into the current and future traffic system. He has been active in the field since 1998 and has been working for Royal HaskoningDHV since 2008, previously working for SWOV and TNO Automotive.

Interviewed persons

Especially for this paper, several prominent professionals in the field were interviewed based on a standard questionnaire. Depending on the expertise of the different individuals, the interviews had specific focal points for further investigation. The interviews were conducted anonymously, and the minutes were used solely as input for the paper. The literature and interviews form the basis of the content presented in this paper.

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Summary

Purpose of the paper
The purpose of this whitepaper is to:
- *Raise awareness* about the implications of the transition to autonomous driving.
- *Stimulate discussion and provide input for the formation of a central vision* that can proactively shape the future of autonomous driving rather than reactively following technological developments.
- Examine the implications for road management and its impact on design, maintenance, and organization as practical *perspectives for action*.

Methodology
Through interviews with leading experts and a literature review, the potential impact of widespread autonomous driving was explored. This whitepaper seeks to identify the transition point from a focus on road design to support human drivers to a focus on the needs of autonomous driving. It aims to create a vision for the future based on current insights and utilize future backcasting to identify key milestones on the path from that vision to the present. The paper also includes storytelling scenarios in five-year increments to depict a fictional day in the life of a character in those years (Part 1). Part 2 of the paper provides more background information and elaborates on the underlying ideas of those scenarios.

Current status
The technical development of autonomous transportation is progressing slowly but steadily. A significant portion of the current vehicle fleet (both passenger and freight vehicles) is already equipped with driving assistance systems like Lane Keeping Support, Intelligent Speed Assistance, Adaptive Cruise Control, and automatic emergency braking systems, collectively known as ADAS (Advanced Driver Assistance Systems).

In the coming years, ADAS will further evolve into more advanced forms of driving assistance and automation, leading to a transition from situations where human drivers are responsible for gathering information and controlling the vehicle to a future where vehicles operate fully autonomously in suitable environments and conditions. Improving traffic safety through automation and contributing to a more pleasant and accessible living and working environment are key driving forces behind these developments.

Why move towards autonomous driving
Beyond advancing ADAS functionalities towards full Autonomous Driving Systems (ADS) and enhancing traffic safety, the introduction of autonomous driving presents promising opportunities in both personal transportation and transport and logistics. Factors such as driver shortages in public transportation and logistics, as well as the technological advantages and opportunities for the Netherlands, make taking direct steps towards autonomous driving appealing.

Additionally, embracing autonomous driving aligns with sustainability goals by reducing fuel consumption through increased efficiency. Autonomous driving could also support the transition to shared mobility and reduced private vehicle ownership, leading to a decreased demand for vehicles, materials, and resources, potentially freeing up space for other functions. It is essential for autonomous vehicles to become an integral part of a multimodal traffic and transport system, forming part of a broader mobility transition.

The desired outcome
The focus of this paper is on infrastructure and the opportunities and implications related to autonomous driving. Envisioning the future (the desired outcome) from policy and user perspectives, the paper works backward to identify the necessary steps in the physical and digital infrastructure to reach that future vision. The desired outcome involves utilizing technological possibilities to establish a traffic and transport system by 2060 that significantly contributes to the quality of life and the living environment. Key elements include traffic safety and social security, livability, accessibility, health, comfort, social interaction between different modes of transport, and an inclusive transportation system that is physically accessible and affordable for everyone, offering seamless, user-friendly, and convenient door-to-door travel.

Relevance of infrastructure
The transition to autonomous driving is facilitated by reducing complexity and decluttering the traffic environment. Gradual reduction of physical elements (road design specifics and DVM-assets) should be considered based on road types, aiming for uniformity and consistency. Road condition is a crucial factor for both automated and human drivers, necessitating a reevaluation and updating of quality standards for maintenance, particularly regarding visibility of road markings and signs in various weather and lighting conditions. In contrast, smart vehicles provide continuous data about the state of assets, enabling more proactive and demand-driven maintenance. It is also crucial to further develop the digital infrastructure to support autonomous vehicles, as it can complement and compensate for the decluttering of the physical infrastructure. The digital infrastructure will function increasingly as a digital twin of the physical infrastructure, employing HD maps (digital navigation maps) as interfaces for vehicles, and connectivity as a

key aspect. The information received by vehicles will be a mix of their own perception, communication with the environment, data, and central guidance.

Impact on Infrastructure Investments:
When considering investments in infrastructure, several principles should be considered:

- Infrastructure should not be extensively adjusted for smart and autonomous vehicles; instead, the vehicles should adapt to the infrastructure.
- To expand autonomous driving, the digital foundation must be in place, ideally real-time.
- If autonomous driving becomes dominant, road design should focus on the requirements and specifications for machine-controlled driving, rather than human behavior.
- Machine-controlled driving demands a machine-readable environment.

  Reducing complexity offers several advantages:
  - easier execution of driving tasks for both human drivers and machines,
  - leading to safer and more comfortable road use;
  - reduced road management costs and complexity;
  - potentially lower and more constant speeds (lower fuel consumption, increased comfort);
  - enhanced uniformity within Europe to accelerate development; digital traffic management for better policy guidance.
  - Simplification of regulations, particularly its fine-grained aspects, eases digitalization and requires less effort.

Steps to reach the desired outcome:
it is important to acknowledge that there will still be much discussion concerning governance and societal acceptance of autonomous driving. However, focusing on the outlined goals and steps provides a path from a future spot, backcasting to now where autonomous driving can play a significant role in improving the quality of life and the environment.
The following steps are necessary to achieve the desired outcome, particularly in areas where autonomous driving is permitted:

9 Further reduction of complexity
Reduce complexity win the environment to facilitate successful vehicle automation and a more comfortable journey.

8 Roadside dismantling
Gradually decrease roadside systems and signage as more information and control is integrated into vehicles directly.

7 Road characteristics
Simplify road characteristics and design since machine-controlled driving does not benefit from elements designed for human behavior, allowing for more comfortable and time-efficient journeys.

6 Which form of steering for which road type
Determine which types of road environments are best suited for machine-controlled driving.

5 Regulations aimed at automatic control
Develop regulations specifically tailored to automated driving, aligning them with vehicle specifications and ensuring that traffic infrastructure and access rules are digitally available.

4 Smart maintenance
Implement intelligent maintenance practices based on data from vehicles, focusing on areas where vehicles indicate difficulties in perceiving the environment.

3 Making traffic signs machine-readable
Make traffic signs and characteristics machine-readable to enable vehicles and people to understand the environment accurately.

2 Digital twin
Establish a digital twin of the physical infrastructure to support the expansion of autonomous driving, aiding human interpretation and assistance as well (ADAS).

1 Reduction of roadside information
Reduce the reliance on roadside information by providing real-time updates through navigation services and directing policy aspects through real-time information (RTTI, VM-IVRA).

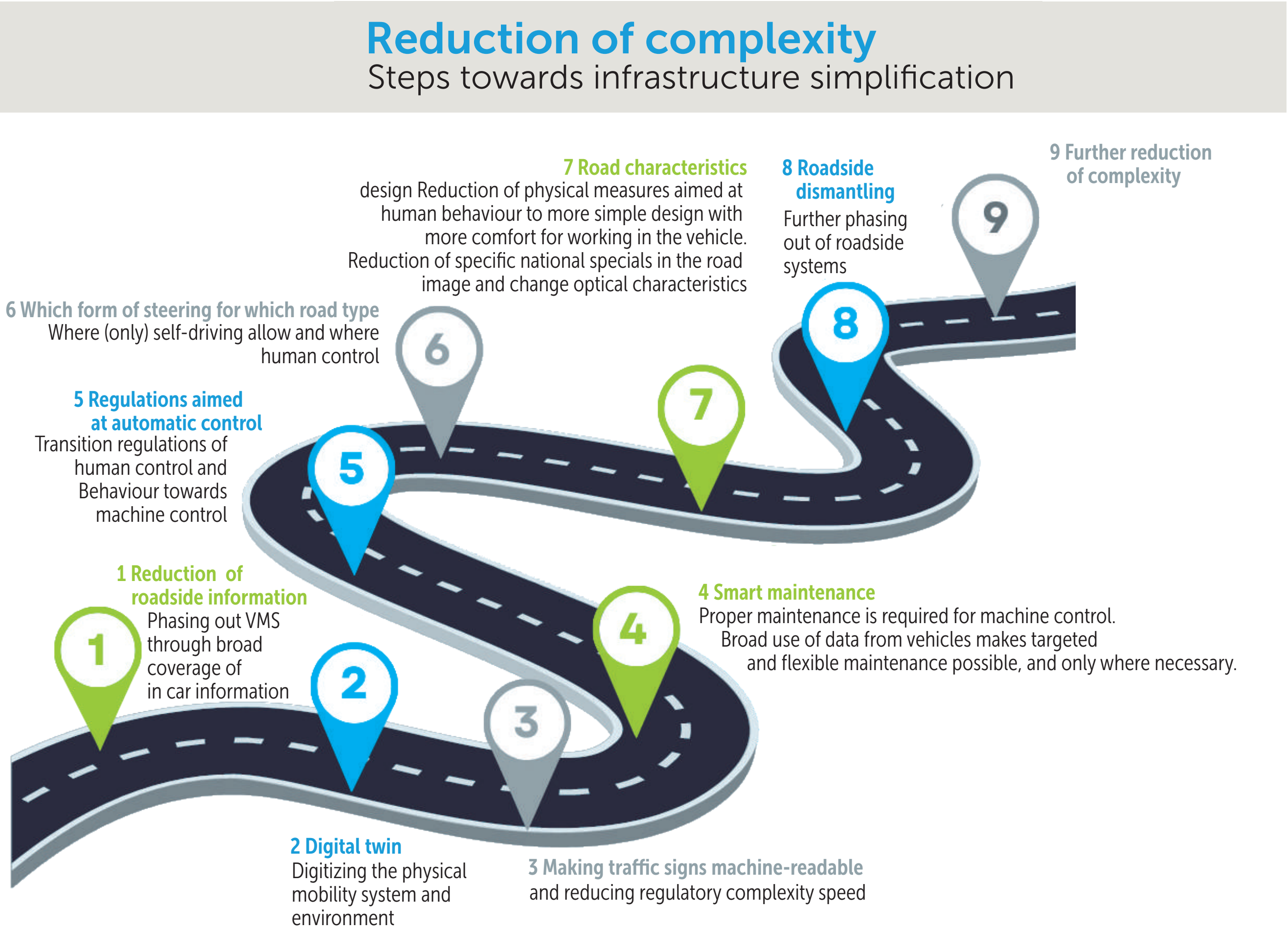


Figure 1. Illustrates the steps from the future to the present (from step 9 to step 1), presenting a potential backcasting path for reducing complexity. This path can be followed from the present, starting at step 1, but the further away the step, the greater the uncertainty.

This path is created based on the current knowledge and intended to facilitate a broad discussion, aiming to make informed and efficient investments in physical and digital infrastructure. Additionally, the competencies and skills of employees at road authorities are also crucial to consider, given their changing role, to enhance the organization's future resilience.

User guide

With this paper, we seek to explore the vision and future scenarios associated with it, aiming to inspire and stimulate discussions on relevant themes. Of course, we are influenced by the present time and the knowledge we currently possess, but we try not to be hindered by it, albeit without the vain hope of predicting the future.

As shown in Figure 2, predictions are most effective when they align with the reality they aim to predict or discover (accurate) and can be focused (precise). However, there are too many factors to achieve high scores in both accuracy and precision. What we do provide are relevant development paths, serving as incentives to move in the right directions proactively rather than passively or reactively.

The scenarios presented in this paper are the result of gathering insights from various stakeholders, literature, policy documents, and the authors' expertise. It is evident from these sources that numerous uncertain factors make it challenging to paint a clear picture. How fast will autonomy develop in terms of technology, acceptance, and costs? Will we ultimately focus on self-driving vehicles or self-driving transport and logistics, and to what extent will this transition be driven by the market or Europe? An economic recession could also delay progress by several years. These and other dilemmas introduce significant uncertainties. Nonetheless, we should not remain fixated on the present. Instead, we must look ahead, dare to dream a little, and shift from reactive thinking about technology, regulations, and systems to focusing on where we ultimately want to end up and why.

The paper is divided into three parts:

- Part 1 begins with a brief introduction to the theme of automated traffic and transport and the approach used to develop the paper (Chapter 1). We describe *the spot on the horizon* (the endpoint) in Chapter 2, inspired by the contributions that automated traffic and transport can make to societal challenges and goals by the year 2060. Next, in Chapter 3, we reason backward from the endpoint in 2060 to the present, using five-year intervals. This "*future backcasting*" approach provides insights into the decision points along the way. To make it more engaging, this chapter also describes the *experiences of various personas* in the successive time periods. Chapter 4 presents an overview of significant observations/highlights to inspire the discussions and ongoing or future development paths.
- Part 2 provides further explanations and insights into the topics covered in Part 1. It offers additional context and backgrounds on the transition from focusing on human drivers to focusing on vehicles and the role of automated vehicles in the mobility transition (Chapter 5).
- Part 3 (appendix) contains the list of consulted literature.

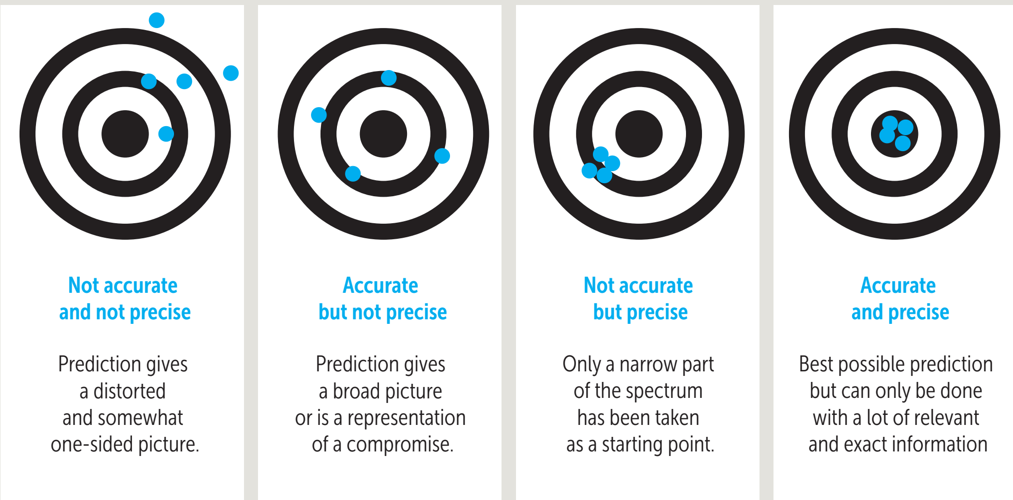


Figure 2. The question is how accurately and precisely the future of the road can be determined. The most important unknown is the lack of information about future developments that are not yet known.

THE HORIZON PERSPECTIVE

Part 1

1 Introduction

The step-by-step development of automated traffic and transport and the influence of infrastructure investments
This whitepaper has been commissioned by the KpVV program and the National Collaboration Smart Mobility, Infrastructure of the Future working group.

We see steps towards fully automated traffic and transport in various parts of the world. Although currently in a small-scale and controlled environment or sharply defined access area, these developments will increasingly extend to Europe and the Netherlands. Moreover, steps are already being taken through EU regulations to allow the use of Automated Driving Systems (ADS).

The desired behavior of vehicles is becoming more achievable through automated driving. This means that automated traffic and transport can significantly contribute to societal and economic challenges related to the quality of our living environment and sustainable, safe, efficient, and inclusive mobility. This applies to the main road network, rural areas facing transport poverty, and cities that are becoming increasingly congested in limited space.

In this transition, there is a shift in the traditional relationship between humans, vehicles, and roads. It moves from a situation where the driver of a car must gather, interpret, and control all information to a period where vehicles operate fully automatically in suitable environments and situations. This changing human-vehicle-road relationship requires a greater focus on the vehicle in the design and functioning of the traffic and transport system. The interaction between smart vehicles and the traffic environment must be carefully examined, along with its implications for the development of physical and digital infrastructure, as part of a responsible introduction of automated transport.

The technical development of self-driving traffic and transport is progressing slowly but steadily. Technology is continuously improving, but for a considerable period, there will still be a mixed fleet of vehicles with varying levels of task automation. At this point, the main spin-off seems to be in the added value of ADAS (Advanced Driver Assistance Systems). As we anticipate that the driving assistance functions currently offered by ADAS will evolve into more advanced forms of task support and task automation, the vehicle will gradually provide increasing support to the human driver. To capitalize on this added value, it is crucial that ADAS function well (in an increasing number of situations) and meet the needs of end-users. This is a collaborative effort involving humans, vehicles, and infrastructure.

However, we must also consider the long-term perspective: what future prospects are emerging, *where do we want to go, and how do we get there?* This is the starting point.

Approach

Seeking the vision
With this paper, we aim to explore the vision: what future perspectives lie ahead and what is involved in the responsible introduction of automated traffic and transport. *Where do we want to go, and how do we get there?* Objectives may vary, and outcomes may encompass both design and policy aspects. To better visualize these future scenarios and the path to reach them, it is helpful to set *a spot on the horizon* and reason backward to identify decision points along the way (*future backcasting*). This approach allows us to gain insights for a general investment strategy (at a high level), supported by a course that prevents disinvestments and aids developments.

On the way back from the landmark to the present, we encounter the turning point from primarily focusing on the driver in the design of the traffic system to consciously shifting more towards the smart vehicle. Eventually, we arrive at the present where our focus is primarily on the driver (how does the human driver interact with the environment).

The quest we initiate with this paper is comprehensive. It goes beyond the scope of this document to delve into all aspects in detail. However, we outline development trajectories and primarily focus on the implications for the design and layout of roads. Questions that arise include: How can we align the infrastructure with the principles of Sustainable Safety to make it less complex, uniform, and unambiguous? And what does that mean for design guidelines and maintenance standards? What role does digitization play, with an increase in digital information about the road and traffic environment? To what extent should we adjust the environment to a speed limit when smart vehicles choose appropriate speeds and speed violations no longer occur? We also observe that the Netherlands has a relatively well-developed (main) road network with a high level of maintenance, providing a solid foundation for smart vehicles to function effectively. However, the complex landscape of speed limits and numerous specialized road designs that cater to human drivers can be limiting, as the internationally operating market may not cater to situations unique to only one or a few countries.

In summary, by focusing on potential consequences for the infrastructure, we expect to provide inspiration and direction for the discussion that we aim to stimulate with this paper.

Gathering state-of-the-art knowledge and experience
To paint the future scenarios, we have gathered state-of-the-art knowledge and experience from various Dutch and international key publications and through interviews with a selection of key individuals working in the broad field of smart mobility. We conducted a literature scan focused on the development paths in existing roadmaps as presented in recent and authoritative (inter)national articles[1]. The interviews followed a predetermined questionnaire and contributed to identifying pertinent questions and dilemmas, clarifying decision points, and potential actions for road authorities, as well as the required stakeholder coordination[2]. Insights from the literature and interviews, combined with the authors' knowledge, have shaped the principles and underlying theme of this paper.

1 See the bibliography in the Annex.
2 See the list of interviewed persons/organisations on page 2.

Central question for the paper
What does the perspective of autonomous transportation look like for the future, given the knowledge we have now? Which design of the physical space/road infrastructure best fits this perspective, and what development paths can we identify?

Purpose of the paper
1. *To create awareness* about the direction and principles towards a world with autonomous vehicles (for different types of road authorities: national, provincial, and municipal).
2. *To stimulate the discussion/vision* in this domain; the paper will present relevant focal points and outline dilemmas.
3. *To provide an actionable perspective* to justify investments in a future-proof infrastructure. This includes illustrating the decision points that will arise on the development paths and the possible actions they may lead road authorities to take or avoid. It will also highlight the necessary coordination with other stakeholders (such as automotive companies) regarding a clear distribution of responsibilities, roles, and tasks.

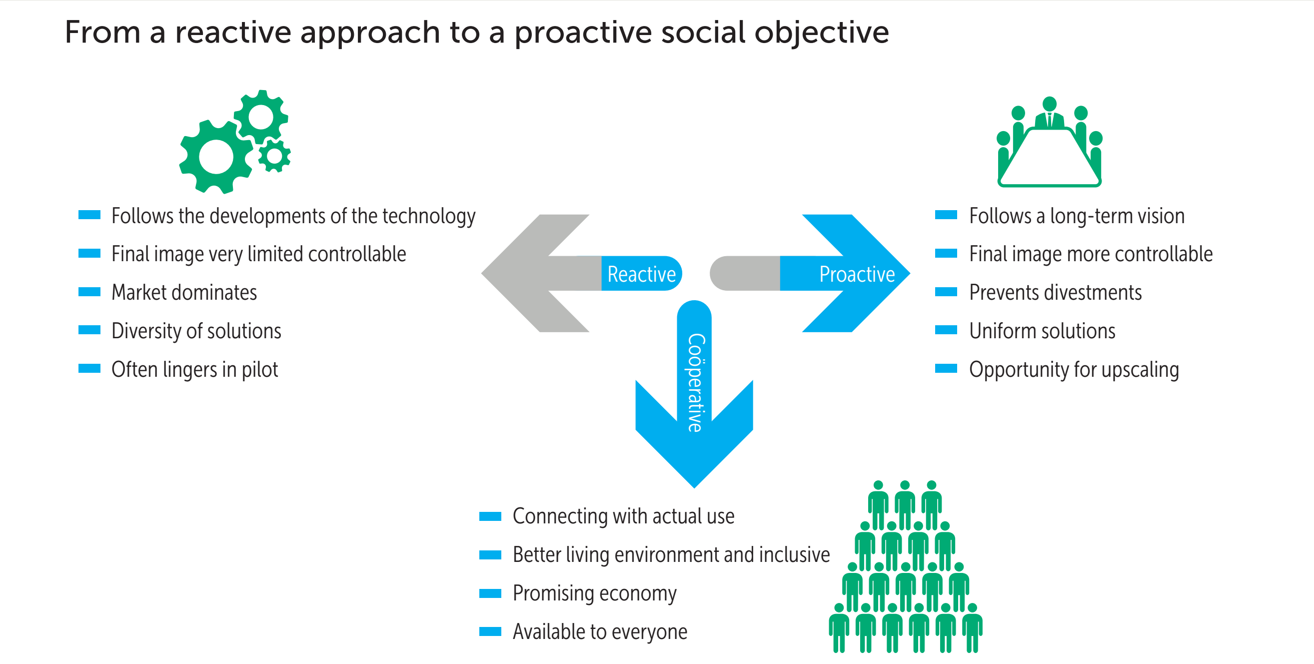


Figure 3. In terms of line, this paper emphatically does not follow technological developments, but focuses on social goals so that the transition does not just happen to governments, but there is more control over the final picture, opportunities for upscaling are greater and divestments are prevented.

2 The spot on the horizon

2060

Technological possibilities have shaped the traffic and transportation system in 2060 to make a clear contribution to the quality of life and the living environment. Central to this vision is not the technology itself, but rather the human with their needs. Key concepts include: Traffic safety and social safety, livability, accessibility, health, comfort, social interaction between modes, with a transportation system that is physically accessible to everyone and also affordable for everyone (broad inclusivity). It should be efficient, user-friendly, and easy to use, offering convenience from door to door.

2.1 Goals

Traffic safety

Significant improvement in traffic safety through automatic control, particularly in areas/roads with a high proportion of autonomous vehicles. Eliminating human errors and undesirable behavior and preventing individuals with insufficient driving capability from participating in traffic as drivers will make the system much safer. Safe speeds can be actively influenced with speed windows, depending on the situation.

Accessibility

Optimal utilization of road capacity through the use of technology. Achieving better control over planned mobility (via smart pricing) and capacity based on some form of reservation. By linking pricing to capacity and prioritizing or exempting certain forms of transport, control can be exercised over the expected increase in vehicle kilometers due to autonomous vehicles, as well as the increase in vehicle hours lost in metropolitan centers due to changing value of time when using autonomous vehicles.

Climate

In general, automated transportation consumes less energy than vehicles with human drivers. Connected, cooperative, and automated vehicles can coordinate with each other and the traffic infrastructure to improve traffic management and reduce congestion. This optimization can decrease energy consumption and emissions associated with traffic jams. The increase in sustainable energy sources further contributes to the reduction of harmful emissions.
Further development and process simplification (based on AI) should reduce the additional emissions generated by computers due to the large number of calculations they perform. Additionally, automated driving appears to be the key to scaling up shared mobility. A significant reduction in

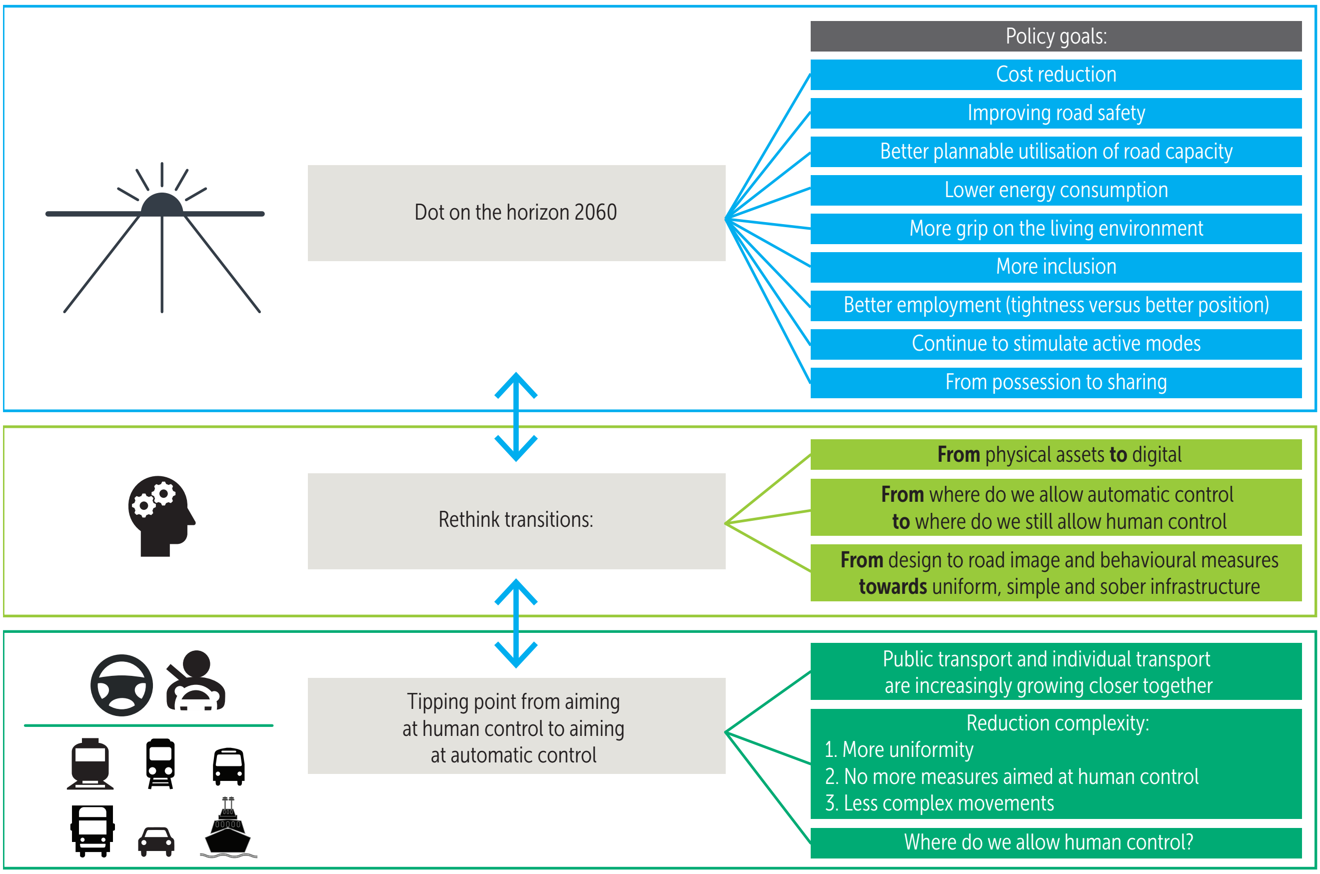


Figure 4. With the goals on the horizon (top) and on the way to the tipping point from focusing on the driver to focusing on autonomous driving (bottom),

private vehicle ownership is more likely when services and applications become so appealing that everyone wants to use them. This would lead to a reduction in the size of the fleet and, consequently, the need for less material.

Livability
Governments gain more control over route and transport choices, allowing for better organization of capacity and reduced congestion. Automated vehicles will not travel through areas where they are not necessarily needed, thanks to socially desired routing and selective access.

Spatial development
The large number of automated vehicles that promote the further introduction of shared concepts and the blending of collective and individual transport will reduce the parking demand in residential areas. Parking will mainly take place at the edges of residential areas and urban areas for private ownership, while shared vehicles will be utilized instead of being stationary. These shared vehicles will be gathered at specific locations (hubs) during traffic-free days or periods. This leads to the alternative use of available space, resulting in a higher quality living environment. There is also less pressure on space in the city as more people choose to live in the periphery or region where travel time becomes part of working time and is, therefore, more effectively spent.

Inclusivity
Automated transportation is available to everyone, including those with physical and financial limitations. It also offers opportunities for personalized transportation for vulnerable groups.

Human-centered approach
The mobility system places the human end-user/traveler and resident at its core. This approach helps the society as a whole with automated transportation.

Cost reduction
The road infrastructure is partly adapted to accommodate smart vehicles, with less complexity and more uniformity and consistency, both nationally and internationally. The reduction of complexity is accompanied by streamlining and simplifying the physical infrastructure, leading to cost savings. However, more effort is required in data and digital traffic management.

Employment
Vehicle automation is implemented to compensate for the shortage of drivers for collective transportation (public transport) and freight transport, creating new technological opportunities and associated employment opportunities for businesses.

2.2 Further description of the traffic and transportation system in 2060

Connectivity and automation
in 2060, vehicles have 100% real-time connectivity on the relevant road network, and the transportation and traffic management system provides the appropriate quality of service, including remote operation. All newly registered vehicles are automated but at different levels. Most functions related to safety and efficiency have been taken over by the vehicle from the human driver. Distraction, inability to divide attention, and traffic rule violations are things of the past.

Vehicles communicate with their environment in three ways:
1 Central: with a traffic manager (for generic frameworks or network control).
2 Decentralized – local: road-side to vehicle (for location-specific information or circumstances).
3 Decentralized – local, vehicle-to-vehicle: for interaction between vehicles.

The Operational Design Domain (ODD) for automated vehicles has been expanded, while the ODD for non-automated motorized vehicles has been reduced.

An optimal balance has been achieved between the possibilities of automation on the main road network and the social-human scale, which is particularly evident in residential areas. The high degree of vehicle automation on main routes allows passengers to use travel time for other activities rather than driving, making congestion less relevant in their perception. The focus is now on reliable, albeit longer, travel times, which are perceived differently. The stable base speed results in little speed variation, creating a smooth journey comparable to train travel.

Multimodal and inclusive traffic and transportation system

There is full integration between transportation modes. The transition from "modal shift" to "modal connection" has resulted in the separation of traffic flows where possible, promoting unimodal flow, traffic safety, and multimodal connection where appropriate. This integration makes the chain journey easily integrated into the system, making transportation poverty a thing of the past.

Modes are synchronized in real-time, enabled by their digital link and physical connection at interchange points/hubs. This allows for tailor-made solutions for all travel and transport needs, significantly reducing transfer time.

The transition from ownership to usage has brought collective and individual transportation closer together, and usage-based payment has led to a better distribution of capacity.

Modal split/shift: collective and individual

For able-bodied individuals, relatively short trips are preferably made by active modes. Collective and individual transport complement each other more (e.g., on-demand ordering of a spot in a shared vehicle). Individually motorized transport remains important, especially in rural areas or regions, but where the transition is desirable, significant attention is given to user-friendliness (hubs). This has led to more car-free or car-restricted city centers that remain accessible from the region.

Road capacity

The increase in vehicle kilometers due to the increased mobility of young people without a driver's license, the prolonged mobility of older people, and those with disabilities having equal travel times compared to others will lead to higher demand. However, the capacity has become more controllable due to planned mobility through smart pricing based on some form of reservation. Technological optimization of road capacity utilization makes this possible.

Parking demand and spatial development

There is increased travel demand but decreased parking demand. Such shifts in parking demand from residential areas to central points mean that parking in direct residential areas becomes less common. Hubs play a vital role in this process. Reduced motorized vehicle usage increases the quality of public space.

2.3 Infrastructure in 2060 compared to now

Road design and layout

When designing and configuring roads, standard consideration is given to automated vehicles by reducing complexity and increasing uniformity and consistency, both nationally and internationally. The physical infrastructure does not require significant large-scale adjustments. The digital infrastructure is highly developed.

- The design and configuration of the infrastructure are based on the fundamental principles: reducing complexity, increasing uniformity, and consistency.
- There have been no compromises on road safety levels, and there is no drastic resizing of road profiles. Accidents will still occur to some extent, necessitating an obstacle-free zone in which the vehicle can ensure its own safety. Some adjustments will still be necessary to compensate for lateral movements caused by strong winds for larger vehicles.
- The decluttering of the traffic environment is complete. The visual quality of the infrastructure has significantly improved as most complexity has been removed, facilitated by the development of connectivity as a strong enabler.
- Public lighting along roads has decreased, and there are fewer traffic lights on the main road network due to conflict reduction at intersections and junctions. In-car traffic regulation and signaling are facilitated by V2X communication between road users.
- There is a network for L4 vehicles to reach their destinations within a short distance.

Integration of physical and digital infrastructure

The physical infrastructure has been complemented by a comprehensive digital representation (twin) serving as the foundation for ODD management (allowing automated vehicles access in accordance with the available service level from the physical and digital infrastructure ISAD), traffic management, and asset management (ensuring optimal utilization of the available road capacity). HD-maps serve as the interface in the vehicle, while connectivity enables the timely provision of accurate information to all road users.

Access to road types/areas

Main road network

- The main network is primarily designed for automated vehicles, and road users can also drive there themselves if supported by a minimal set of ADAS, connectivity, and intelligence that assists the driver. Vehicles falling under the category of oldtimers are restricted from accessing the Main Road Network.
- Active and motorized modes are separated on the main road network.

Subsidiary road network

- The subsidiary road network is a mix of roads where vehicles can travel automatically and roads where drivers drive themselves.
- On the subsidiary road network, conflicts between motorized and active modes persist in many locations.
- Intersections are mainly designed as roundabouts (arguments: reducing complexity and decluttering of infrastructure).
- Traffic calming measures, such as speed bumps, are no longer applied.

Residential areas and living zones

- In residential areas and living zones, roads are primarily designed for human road users due to the complexity for AVs and from a social perspective. Parking spaces for private cars in residential streets are no longer necessary. Transition from active modes (walking, cycling) to motorized modes is accessible within 5-10 minutes. Automated vehicles also park outside the residential area after dropping off the passenger/owner (e.g., for people with disabilities). A decrease in parking occurs, especially in cities where space is limited and other busy living or event areas. Streets are designed to allow for occasional access for emergency services, moving trucks, or goods delivery.

Capacity
Highways are flexibly designed to optimize the available capacity according to varying demand throughout the day (tidal flow).

Spatial development
more space is needed at interchange points of modes/hubs for parking and services to enhance the attractiveness of the hubs. Urbanization around such points is limited.

2.4 CCAM as optimization or transition?

In the existing triangle of humans, environment, and vehicles, the position of humans within that triangle will change significantly on the path to Connected, Cooperative, Automated Mobility (CCAM): from driver to traveler or passenger. The key question is how humans will use the new system.

With a radical change like this, it is not obvious to think from the perspective of the existing system. A true transition involves reevaluating what is truly needed and how users will ultimately interact with it.

Infrastructure
As we gradually allow only machine control in the future, the focus will shift from human control to machine control. This shift can already begin to take place with a certain density of machine control in traffic (see S-curve, Figure 11).

On roads where only autonomous driving will be allowed, what will be necessary? Many elements in road design are

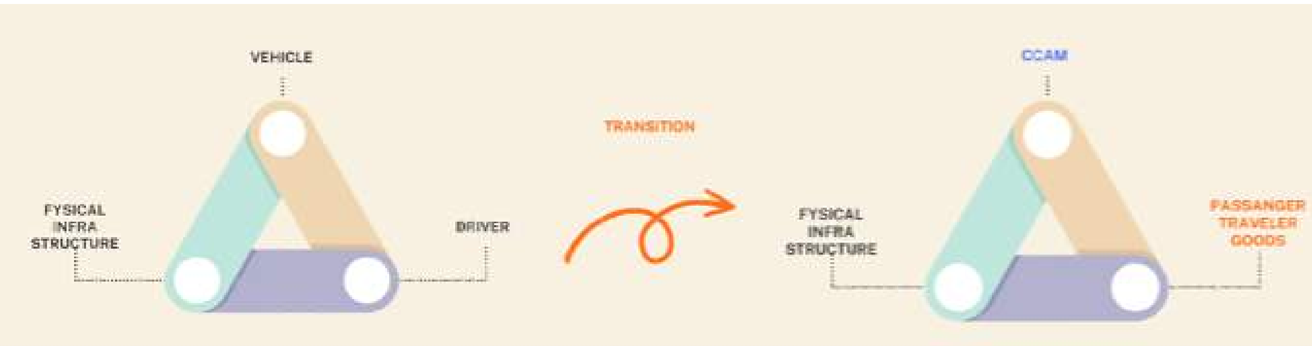


Figure 5. In the infra-vehicle-human triangle, we see the position of humans in particular changing significantly due to the automation of the vehicle.

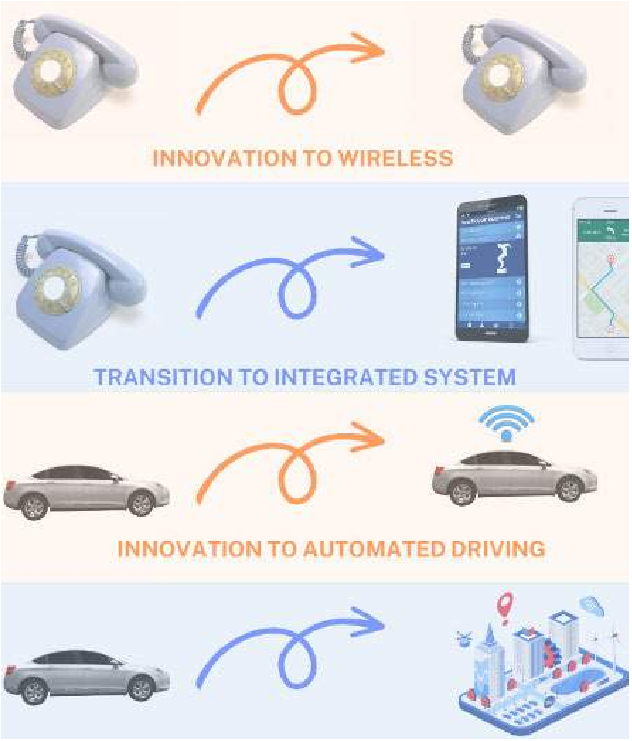


Figure 6. The innovation from the landline telephone to the mobile has ultimately led to numerous services that could not be imagined beforehand. The innovation from human control to machine control could well lead to a completely different mobility system, provided that services are created that everyone wants.

based on influencing human driving behavior. Aspects such as optical narrowing, road appearance in conjunction with function and regulated speed, etc., are all less necessary or unnecessary for CCAM. Some assets will also become redundant (such as signage and traffic control for congestion). Depending on the development of CCAM, other elements may not be necessary in the long run. However, more effort will be required in terms of data exchange between traffic infrastructure and vehicles. This effort may eventually decrease with the application of AI and V2V communication. Nevertheless, some government regulation will still be necessary.

A reduction of elements from the road environment will also benefit public transport and emergency services. We may eventually realize that if people still want to drive themselves, it could be costly in terms of road design, potentially accelerating the transition. Insurance companies can also have an accelerating effect by reflecting the reduction of accident costs for automated vehicles in premiums.

Cars and trucks have not completely replaced horse-drawn carriages, but we have not considered this recreational form of mobility in road design for a long time.

Now: "**We won't adapt the road for smart vehicles, but smart vehicles will have to adapt to the road.**"

Future: "**We will no longer invest in expensive resources for human control...**" (on routes/areas where automated vehicles dominate traffic participation)

The table below provides an impression of what is necessary, depending on the form the transition ultimately takes. Looking at the CCAM column: if you were to construct a new road, a hardened and comfortable surface (asphalt) would be needed as a base. In addition, good data is essential, but there may be much less support required from the hard infrastructure than we are used to now. The table below provides an impression of this.

Human and vehicle behavior

Human control seems to have both advantages and disadvantages. In heavily mixed traffic, social and defensive driving behavior becomes increasingly important. A self-driving vehicle will not quickly allow someone to cross the road to catch a bus. On the other hand, if a self-driving vehicle is allowed to go first at a busy intersection by another vehicle, it might not know how to respond. However, human behavior also has disadvantages. People tend to exceed speed limits, use substances that can affect driving ability, and can sometimes display aggressive behavior. Self-driving vehicles do not have these characteristics and dutifully follow route advice for policy-based routing, for example. Provided the data is accurate since, in the worst case, this compliance also carries a certain risk, namely the lack of insight and logical thinking. AI may be able to partially address this issue.

Table 1. To support human control and to generate the desired (follow-up) behavior, many physical elements in the infrastructure are needed. Mechanical control (CCAM) seems to need a much simpler design due to preparatory techniques and a reduction in design makes the introduction of self-driving on assigned routes a bit easier.

Infrastructure			
Element	**Human control**	**CCAM**	**Explanation**
Pavement	Red	Red	
Road signs	Red	Yellow / Green	Vehicle observation or based on data
Road Marks	Red	Orange / Yellow	Own observation or edge detection and positioning
Traffic lights	Red	Orange / Green	Mixed traffic or unbundling
MTM	Orange	Green	
VMS	Yellow	Green	
Signage of route	Red	Green	
Speed inhibiting measures	Orange	Green	
Optical narrowing	Orange	Green	
Relationship between speed regime and road image	Red	Green	
Public lighting	Orange	Yellow / Green	
Data	Orange	Red	
Digital traffic management	Orange	Red	
Parking	Red	Red / Yellow	Increase of shared mobility
Redressering	Orange	Yellow / Green	
Obstacle-free space	Orange	Yellow / Green	

Legend: Elements within the road layout:

Red – Orange – Yellow – Green

necessary ... not needed

Table 2. Of course, people also have advantages. Defensive, social and practical driving are human skills that are currently lacking in self-driving. On the other hand, undesirable human behaviour is decreasing.

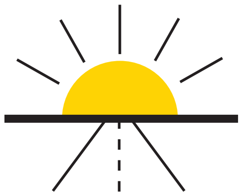
Human behaviour and vehicle behaviour			
Item	**Human control***	**CCAM**	**Explanation**
Social driving behaviour	Green	Orange	F.i.: leaving someone who doesn't really have priority
Defensive driving behaviour	Green	Orange	F.i.: stop in time for a long vehicle approaching a sharp bend
Communication with road users	Green	Orange	Nonverbal communication
Anti-social driving behaviour	Yellow	Green	
Traffic dispute (road rage)	Yellow	Green	
Traffic insight	Green	Orange	If it can't be done the way it should be, then it should be done as it can
Omgang met verkeersdeelnemers met een beperking	Green	Orange	Voor laten gaan van personen die moeilijk ter been zijn of visueel gehandicapten
Funeral procession	Green	Orange	
Military column	Green	Orange	
Specific tram trafficrules	Green	Orange	
Follow-up behaviour, rules and advice	Orange / Yellow	Green	Following advice in terms of routing, speed
Use of alcohol and drugs	Yellow	Green	
Distraction	Orange	Green	Depending on road situation in human control
Stressors	Orange	Green	State of mind, sneezing etc
Hurry or restlessness	Orange	Green	

*) Can vary significantly per person (skill may vary, but certainly the willingness to).

Legend: Ability to exhibit desired behavior:

Red – Orange – Yellow – Green

Not skilled ... skilled



Travel experience

Besides driving behavior, there is also the travel experience. If self-driving takes a real leap, for example, because services emerge that we cannot currently imagine, and they significantly enhance comfort and convenience, suddenly everyone may want to have them, accelerating the transition. The mobile phone took a real leap not just because it was wireless, but because we could send text messages. Later, various applications were added that gave the phone a completely different function, and society now assumes that everyone has one (the first clear indication was the disappearance of the public phone booth). See Table 3.

Vehicle performance

Finally, there are the characteristics of human control versus machine control that influence the environment. See Table 4.

Currently, there is still a debate about energy consumption due to the high computing power required for self-driving, but there is consensus that this will be a temporary issue.

Vehicle sharing is a tricky aspect. We are not eager to compromise on comfort, which is often the case with sharing, unless it can be significantly smarter than the sharing we know today. Autonomous vehicle sharing seems plausible, partly because of cost considerations, but with sufficient mass production, costs will quickly decrease, potentially making private ownership affordable. However, a completely different service system may emerge that could partially eliminate private ownership, such as the creation of services around CCAM that everyone ultimately wants to have. Here, there seems to be an opportunity for public-private collaboration (policy and services). Transitioning to a smaller fleet could be a challenging step for the automotive industry, where government guidance may be necessary.

Table 3. As a passenger, the traveler will experience the journey and the time that travel requires differently.

	Travel experience	
Item	**Human control**	**CCAM**
Experience of travel time	Time matters	Different time experience possible because time can be spent differently than driving a vehicle
Comfort	Limited importance	Important so that one can indeed do other things during driving without getting car sick.
Willingness to share	Limited preparation	More often prepared if offered as a service
Travel time per person	Stable	Can get longer without a policy because of an increasing demand from young people who become mobile earlier, and older people who can stay longer. Self-driving can also be an alternative to active modes, unless there is good policy that steers this from an inclusive perspective.

Table 4. Possible effects on climate, environment and safety of CCAM.

	Vehicle performance	
Item	**Human control**	**CCAM**
Energy consumption/emissions	Possible higher consumption due to higher and less stable speed	Possibly lower due to efficiency and stable speed
Sound	Possibly higher due to more acceleration and braking movement, possibly higher speed	Possibly lower due to more composed driver behavior
Road safety	Possibly worse (but people also avoid mistakes)	Possibly better
Material use	Mostly private owned vehicle so large fleet	If CCAM is perceived as a service that favors vehicle sharing, the fleet can be much smaller, resulting in less material required to manufacture that fleet.

3 Future backcasting

In this chapter, we take a journey back from the spot on the horizon to the present day. At various points in time, we pause to envision a day in the life of a traveler, a traffic control center employee, a retiree, and other fictional characters. Through this backcasting, we invite the reader to immerse themselves in those times and reflect on them with the knowledge of the present.

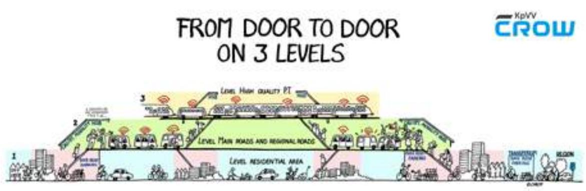
2060

Self-driving vehicles have become a widely recognized and adopted phenomenon by 2060. Most safety and efficiency functions have been taken over by the vehicles from humans. Distractions for drivers, difficulties in managing attention, and traffic rule violations are things of the past. There has been a drastic improvement in traffic safety and utilization of available road capacity compared to 2020.

The safety standards of road design meet the highest specifications, fully integrated with the requirements of automated vehicles. Highway shoulders are free of obstacles (there is little need for protective barriers). Complex road design situations that automated vehicles cannot handle are rare. Incidents or unforeseen situations can be handled by the automated vehicles themselves, in coordination with the traffic manager. Dynamic Traffic Management (DVM) assets such as Variable Message Signs (VMS) and Traffic Data and Information (TDI) systems have been largely dismantled. They might still exist in a few strategic locations or intersections.

Full automation is primarily limited to the main road network, while the secondary road network (especially local roads) still features mixed traffic, where only a limited number of vehicle types operate in fully automated mode under specific conditions (e.g., buses for collective transport and taxi services).

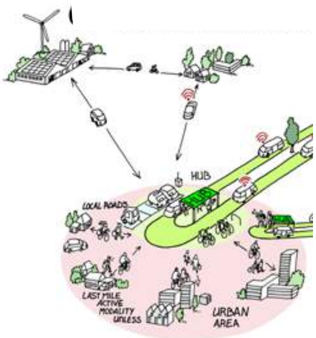
Thus, a certain hierarchy has emerged in the network, with collective and individual transportation converging.



The main, heavily loaded lines in the network are primarily used by public transport, utilizing larger vehicles or electronically linked clusters (ad-hoc or pre-arranged) of smaller vehicles. Due to low costs, the frequency of service is high during the day, and some of these vehicles perform transportation tasks during off-peak hours and at night. Point-to-point goods transportation and hub-to-hub passenger transportation are partially intertwined, resulting in increased road capacity with fewer vehicles. This mode of transport occurs predominantly on major highways and urban corridors, alongside rail transport (which is not covered in this paper).

The thinner lines are filled in more by on-demand transport services. A broad shared mobility concept with smaller vehicles (individual or in clusters of a limited number of electronically linked vehicles) operates between hubs, facilitating rural-to-rural travel without burdening the city, or serving as a connection between the origin/destination and the thicker lines. This form of transport is mainly found on access roads to various areas and regional highways.

The link between neighborhood hubs, city-edge hubs, etc., and the origin/destination is primarily served by active mobility modes for individuals living within a 10-minute distance from such a hub. For those who live further from a hub, have difficulty using active modes of transport, or when social safety does not permit (e.g., during darkness), short-distance transportation can be provided by small vehicles. This mostly applies to residential access roads in urban environments that are designed to limit car usage, unless necessary. Due to the reduction in private vehicle ownership, parking demand has significantly decreased and is primarily available on private premises.

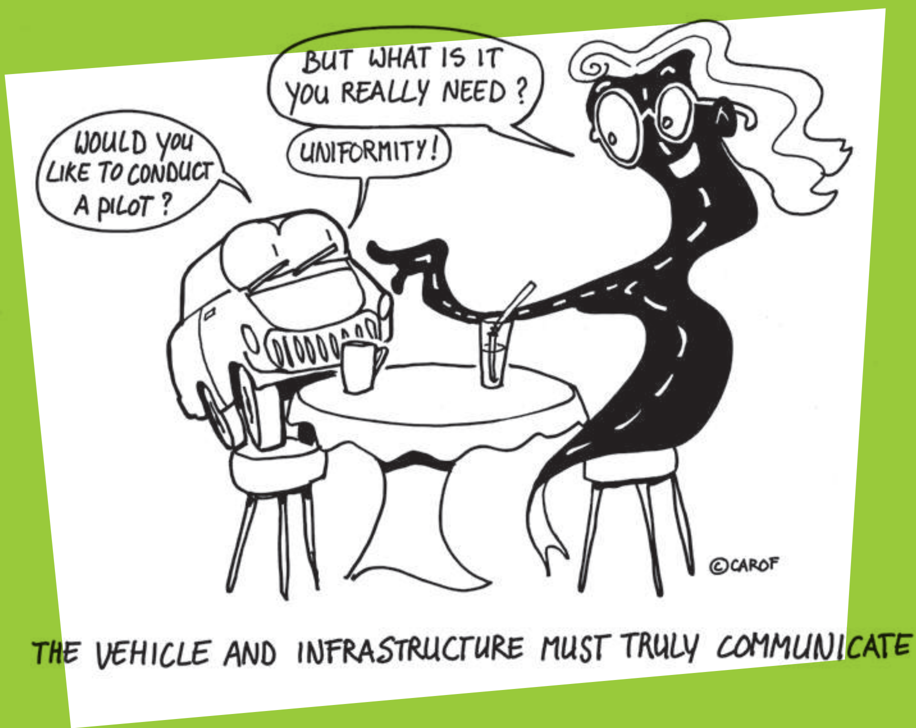


For an overview, see page 70.

A Day in 2060

Thomas (75) recently received a notice from the DMV for a driving proficiency assessment in accordance with Article 183, Section 2 of the Driving License Regulations. He decided it would be safer for himself and others to convert his driving license to only apply to category i (backup self-driving). This category means that Thomas would only drive manually if the technology fails, solely for the purpose of safely bringing the vehicle and its occupants to a stop. For Thomas, it's reassuring that he can still maintain mobility by using the self-driving car. These vehicles are easy to reserve, especially because he chooses the lower rates during off-peak hours.

Later that afternoon, Thomas was busy with an online order for his eldest daughter's upcoming birthday. He opted for the "pickup at the mobility hub" option, which saved him on shipping costs. When you pick up your package at a store located in a mobility hub, there are no shipping fees, but there are fees for home delivery. As a result, the number of package delivery vehicles in residential areas has significantly decreased in recent years. Thomas already knows he will be at the hub on Thursday, so he can pick up the package then. He thinks that mobility hubs look very different nowadays. They used to be large parking lots, but now there are only a few entry and exit lanes as the self-driving cars continue with other customers. What used to be parking space has now been redeveloped with various services, making the mobility hub increasingly attractive for facilitating the transition to collective transport. Once at the hub outside the city, it's more appealing to switch to a train to the metropolitan area than at the urban hubs. The urban hubs are also increasingly used for parking vehicles owned by residents. It's great to see that integrated policy is now truly tangible: more safety through autonomy, fewer movements due to parcel services, reduced parking space in cities, and better functioning hubs, both urban and rural, providing an increasingly better connection between individual and collective transportation. With this multimodal journey, we see that different modes of transport are genuinely interconnected, providing user-friendly experiences aligned with desired behavior!



2055

In 2055, the network of mainroads will only be used by vehicles that can operate automatically and cooperatively. Highways are flexibly designed to optimize capacity based on varying demand throughout the day (tidal flow). Tidal flow involves the dynamic separation of traffic flows in the same direction.

The quality of road infrastructure meets very high safety standards. One aspect involves reconsidering the design elements in the longitudinal and transverse profiles, such as the obstacle-free zone and curve radii. Median barriers with protective measures are fully adapted to the characteristics of automated vehicles. Objects in the roadside that vehicles might collide with in rare cases are designed to be collision-friendly.

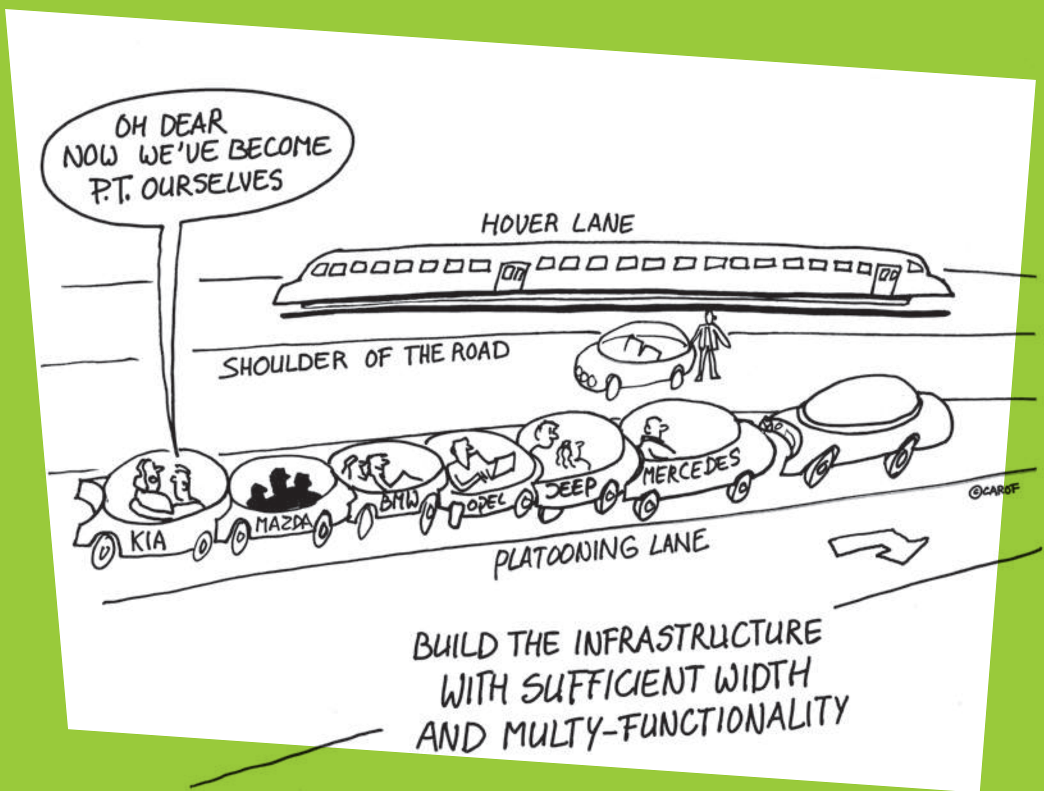
A Day in 2055

Zeynep, 27 years old, works in a laboratory. She enjoys riding motorcycles as her hobby. She notices that more and more road segments are designated only for automated transportation, and sometimes motorcycles are no longer allowed on certain routes. Near the hospital, she observes that mainly autonomous public transport operates, making it impractical to store her motorcycle at a hub.

During a break, she discusses this with her colleagues. Jan also enjoys motorcycling but takes long tours. It's not as fun as it used to be when motorcycles made sounds, but riding by yourself is still enjoyable, although those automatic speed windows can be annoying.

Another colleague shares her positive experience with using a shared autonomous car. With all those automated features, I do all my administrative work on my way back, and I get home an hour earlier. We can often have dinner together at home, which is fun and pleasant.

"I do the same, but on the train," says another colleague at the table. Zeynep laughs and says, "Well, I don't have any train tracks nearby, so I might have to wait a long time for a train."



2050

Further development of digital infrastructure:

- In 2050, there is a high density of vehicle connectivity, traffic calming measures and signs almost unnecessary on main roads. Speeds are used as a digital window based on conditions (weather), capacity, and traffic density, ensuring there is always an appropriate speed limit that is followed.
  All vehicles have V2X communication to drive in ad-hoc pelotons. All vehicles have an HD map fed by a digital twin with information about the road, signage/routes, and conditions.

Adjustment of design and layout – further reduction of physical elements:

- Physical traffic lights at signalized intersections have largely been replaced by in-car information. Traffic signs only exist at strategic locations and serve as a backup. Street lighting along main roads has been mostly removed (except for rest areas). Barrier systems/guardrails are still necessary at locations with an increased risk in case of technology failure.

Separation of road users based on mass, speed, size, and direction is extensively implemented in the design of the road infrastructure. In line with this, the design and layout of intersections have also been further adapted.

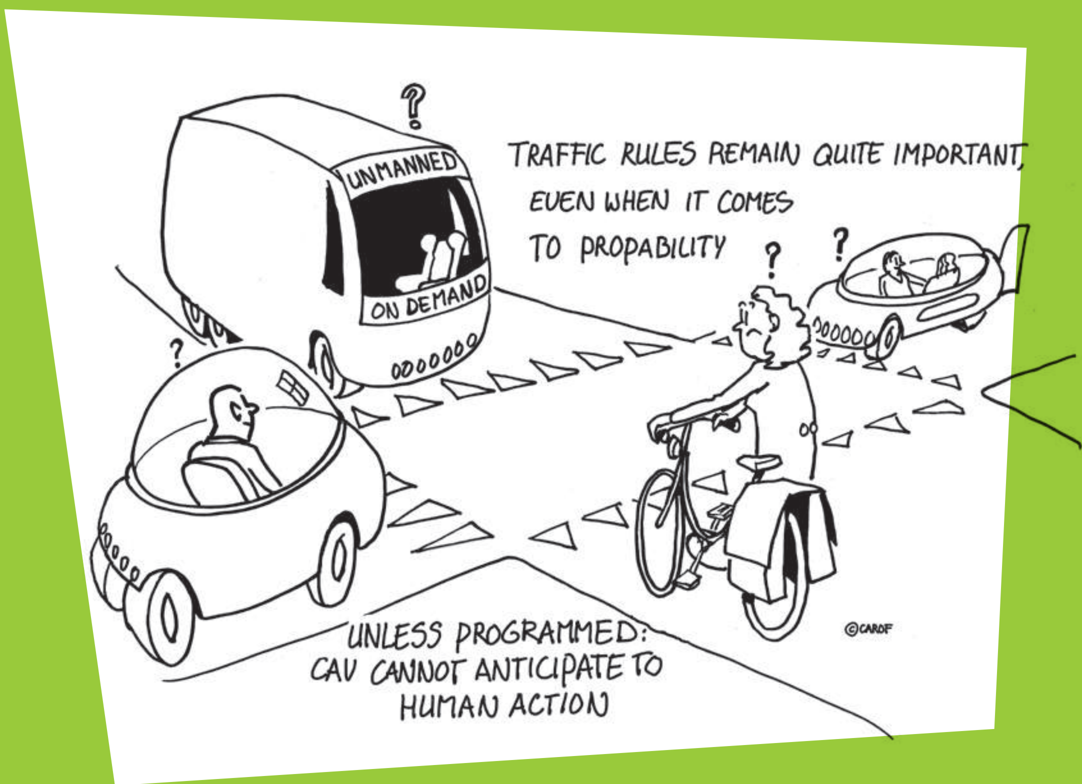
Separate lanes for self-driving vehicles have been established as the market share of automated vehicles is significant enough to utilize these lanes effectively.

Automated trucks operate on all major freight corridors. The Automated Transport corridors function as point-to-point operations within established time windows. Plan infrastructure for point-to-point transport with suitable ODD (Operational Design Domain) from exit to point and from point to entrance.

A Day in 2050

Johan is turning 17 today. "Since we used to get our driver's license as a gift at this age, you'll receive a Multimodal Travel Pass Europe, which should be sufficient for the first few years," his father laughs. Johan's father shares his experiences as a cyclist with self-driving vehicles. "You could always go first, as they would stop anyway," he says, smiling.

However, Johan notices that things have changed. In more and more areas, there are no cars at all, and in places where they are present, cycling is not allowed. It seems quite clever, he thinks. "But how come there are still occasional cars driving on roads meant for cyclists?" Johan asks his father. His father had read in the newspaper that these are mainly vehicles with people who have disabilities and cannot use a bike or walk, or in areas where public transportation is scarce. Johan looks a bit puzzled and thinks to himself, 'Well, then the fun is gone. You wouldn't purposefully walk for such a vehicle; you just wouldn't.'



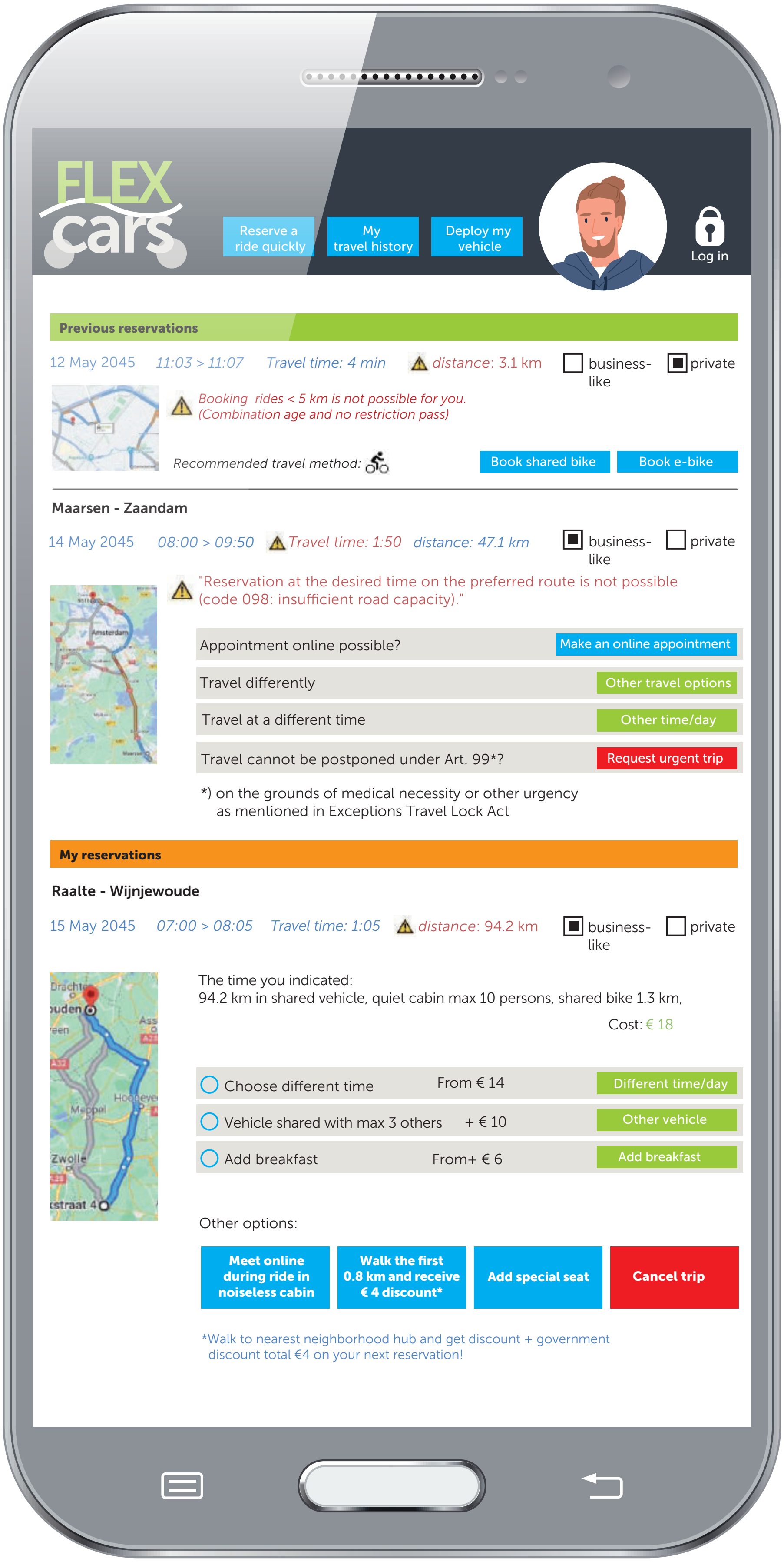


Figure 7. A fictitious example of a digital system for reserving mobility resources with interaction of policy goals.

2045

Further development of digital infrastructure:
- Communication and positioning systems have been sufficiently deployed (precise, fast, reliable, and redundant) to offer 99% level of service on the main road network.

Adjustment of design and layout / reduction of physical elements:
- Smart roundabouts are increasingly in use. Road signage is now only present at strategic points.
- The the main road network network is equipped with facilities (such as breakdown bays) required by automated vehicles for executing a Minimum Risk Manoeuvre.

Multimode:
- Automated vehicles fill gaps in public transportation in rural areas.
- Following the implementation of the Multimodal Digital Mobility Services (EU) in 2025, there are increasingly well-functioning reservation systems that serve both the customer (end-user) and policies.

Maintenance regimes per road type are fully aligned with the vehicles that are allowed. Plan infrastructure for inclusivity and affordability, especially where there appears to be no business case for the market.

A Day in 2045

Bart is a 19-year-old student living in a small fortified town with limited space for cars. His family uses the car for storing energy from solar panels during the day, which can sometimes be challenging. Bart has a different perspective, saying, "In the city center, you can't even go with a car, and people live there. They only have the batteries, not the car," he chuckles.

Today, Bart has to head to his new internship address. He was supposed to use his father's L4 car for the first day, but his father changed his mind as he needs to respond to a sudden work emergency. Bart then decides to order a budget robotaxi. If he shares the vehicle with other travelers, it becomes very affordable, allowing everyone who needs it to use it. The hub Bart needs to go to is too far to bike, and there's not enough public transportation yet to reach the new megahub near Deil junction. From Deil, he can take intercity trains in any direction, making it the place to be, and due to the demand, the robotaxi for this ride is very cheap. Arriving in Amsterdam, he completes the last part of the journey with a shared bike.

The outbound journey goes smoothly, and his first day at the internship passes quickly. The autonomous intercity train from Amsterdam operates at high frequency, and he's back at the hub near Deil junction in no time. He still has time to visit his friend from school. The robotaxi drops Bart off at the autonomous water taxi, which covers the last leg across the Waal River. He can also use this service to get home later and walk the last bit.

Having previous experience with the booking system, Bart now knows it well enough to use it quickly.

2040

Progress of CAV use cases:

- All vehicles have a limiting form of ISA.
- 90% of sold vehicles are highly automated or capable of fully autonomous driving (within ODD, which is gradually expanding). Approximately 25% to 50% of vehicles on the road are highly automated. Access for these vehicles is limited to certain areas as part of the type approval process.
- Most vehicles are equipped with advanced L4-ALKS. In combination with (C)ACC, ALKS systems have evolved into L4 self-driving systems for passenger cars, public transportation (PT), and goods transportation, usable on most Dutch roads.
- Automatic vehicles drop off passengers/owners and park outside the neighborhood/residential area.
- Autonomous/teleoperated hub-to-hub transport: A network of multiple routes for Automated Transport is deployed. In 2040, autonomous trucks shuttle between several major fleet owners as part of standard processes on the Dutch Tulip corridors, connecting major freight terminals. This helps address the labor shortage in goods transportation and cope with the growth of goods transportation by efficiently utilizing road capacity through autonomous night transport. Automated goods transportation also operates on terminals, yards, and industrial areas, resulting in efficiency gains, contributing to a strong and competitive logistics sector in the Netherlands. The connections between these points are handled by human drivers who also play a role in load transfers.
- First ad-hoc platooning of automatic passenger cars on the main road network (HWN) is operational (point-to-point).
- Autonomous public transportation on dedicated (bus) lanes: passenger transportation on dedicated bus lanes outside and at the edges of cities (main road network and tangential routes) is automated. In city centers (radials), the buses operate with manual control. This represents a significant step towards reducing the operational costs of public transportation.
- Automatic buses connect major hubs. From these hubs, additional, demand-driven, or high-frequency (small-scale) automatic transportation is an integral part of the transport solution for sparsely populated, rural areas, and the accessibility of economic top locations.
- Last-mile transportation to and from economically significant locations: most transport to and from economic top locations on the last/first mile is conducted with autonomous vehicles. For example, from PT hubs or terminals to residential areas, industrial areas, and campuses with good transport value. The automatic vehicles travel in mixed traffic without negative effects on traffic flow, sustainability, and traffic safety. These routes are particularly relevant where public transportation is no longer available or where car traffic is discouraged to ensure accessibility.
- Demand-driven autonomous passenger transportation in sparsely populated/rural areas: extensive automatic transportation is available as part of concessions to keep public transportation affordable and inclusive in sparsely populated areas. Autonomous shuttles operate in mixed traffic without negative effects on traffic flow, sustainability, and traffic safety.

Significant advancements in digital infrastructure:

- Digital laws and regulations, including speed limits, are available for the entire road network.
- Digital twins are available for all roads, enabling vehicles to autonomously navigate with information about the traffic environment and road conditions. Vehicle behavior is personalized based on vehicle characteristics. For instance, a vehicle will adapt its speed accordingly to navigate through a curve safely.
- At intersections, fewer vehicles require traditional traffic light systems, as the control information is also available in-car.
- Significant progress has been made in the operationalization of connectivity (vehicle-to-vehicle and vehicle-to-infrastructure) with high service priority for corridors with critical traffic and transport functions.

Adjustment of design and layout / reducing complexity / phasing out physical elements:

- Complexity in infrastructure has been significantly reduced. No new physical traffic calming measures are being installed.
- No parking spaces for private cars in residential streets in busy cities.
- Road signs along the road are becoming less necessary.
- Roadside systems are being phased out.
- Smart Mobility (regarding automatic transportation) is a fixed component of projects within the National Infrastructure Investment Schemes.
- Pricing based on mode of transportation (shared/individual) and availability (capacity) has been introduced.
- Road maintenance is carried out not only periodically but also on-demand based on a continuous flow of data from vehicles.

A Day in 2040

Alwin is 35 years old and works for a company specializing in smart traffic solutions. One of his key focuses is simplifying, streamlining, and standardizing roads. "Smart vehicles demand dumb roads," Alwin often exclaims with a resigned laugh that seems to be natural to him. The adoption of L4 automated driving is gradually picking up speed. Alwin himself owns such a vehicle and wonders how we can achieve safe automatic navigation through intersections. He remembers a rainy Tuesday afternoon when he had been waiting at a busy intersection for a long time to make a left turn until someone finally allowed him to merge in. Alwin thought to himself, "Well, it's a good thing we don't have fully automated driving here, as those vehicles mostly adhere to the rules."

But the idea keeps bothering Alwin. There must be a simpler solution. He realizes that the left turn movement is the challenging part. On a roundabout, you can only turn right, so that issue doesn't exist, but then the capacity becomes a concern. Suddenly, he recalls an old idea of the smart roundabout (SYROPS). It involves multi-lane roundabouts that locally indicate to vehicles coming from a specific direction when they can enter. There is still a two-light signal for non-autonomous vehicles and motorcycles. Alwin's smart roundabout functions like a rotating platform, allowing vehicles from different directions to take turns entering the roundabout. With current technology, this approach should work well and be safe.

Cyclists can take advantage of the gaps created in the model that Alwin has developed. "This way, we combine the safety of a roundabout with the capacity of an intersection and a complexity that suits a good user experience for self-driving PT, logistics, and passenger transportation," Alwin explains. "Moreover, roundabouts as a form of intersection contribute to the 'decluttering' of the traffic environment. And with the almost completed electrification of the vehicle fleet, emissions are no longer an issue." He continues, "This is a logical step after the elimination of tapers, HOV lanes, and special lanes in the road network, which unnecessarily complicated driving for both humans and machines."

2035

Progress in use cases:

- First applications of robotaxis in the Netherlands. Operating within a limited time slot (evening/night) and in a specific area designated for these vehicles. These are shared, electric level 4 vehicles.
- First applications are fully operational for automatic vehicles connecting public transport links in urban areas (part of multimodal transport) / last-mile passenger transportation to and from economically significant locations / demand-driven autonomous passenger transportation in sparsely populated/rural areas.
- Autonomous public transport on segregated bus lanes: autonomous buses operating on dedicated bus lanes outside and at the periphery of cities (main road network and tangential routes) with manual control in city centers (radials).
- At certain locations, automated buses connect key hubs. From these hubs, additional demand-driven or high-frequency (small-scale) automated transportation forms an integral part of the transport solution for sparsely populated, rural areas, and the accessibility of economic centers.

Expansion of digital infrastructure:

- Geofencing is being increasingly applied for access regulation and limiting driving speeds at various locations.
- The basic network for vehicle-to-infrastructure communication is fully deployed.
- All new vehicles are equipped with V2X communication to share traffic-related information with other road users (for traffic safety) and traffic managers (for traffic information, guidance, and control).
- More information from the road and traffic environment, necessary for safe and comfortable vehicle operation, is made available inside the vehicle. This is achieved through a combination of in-car sensors and communication (vehicle-to-infrastructure and vehicle-to-vehicle). Procedures have been developed to prevent conflicting, non-uniform, or unauthorized information.

Adaptation of design and infrastructure / complexity reduction / phasing out physical elements:

- Complexity in infrastructure is progressively reduced. No new physical speed restrictors are being installed.
- No more parking spaces for private cars in residential streets in busy cities.
- Road signs along the road are decreasing in necessity.
- Roadside systems are being progressively phased out.

Smart Mobility (regarding automated transportation) is integrated as a fixed component of projects within the National Infrastructure Investment Schemes.

Pricing according to mode of transport (shared/individual) and availability (capacity) has been introduced.

Road maintenance is no longer only periodic but also demand-driven based on a continuous flow of data from vehicles.

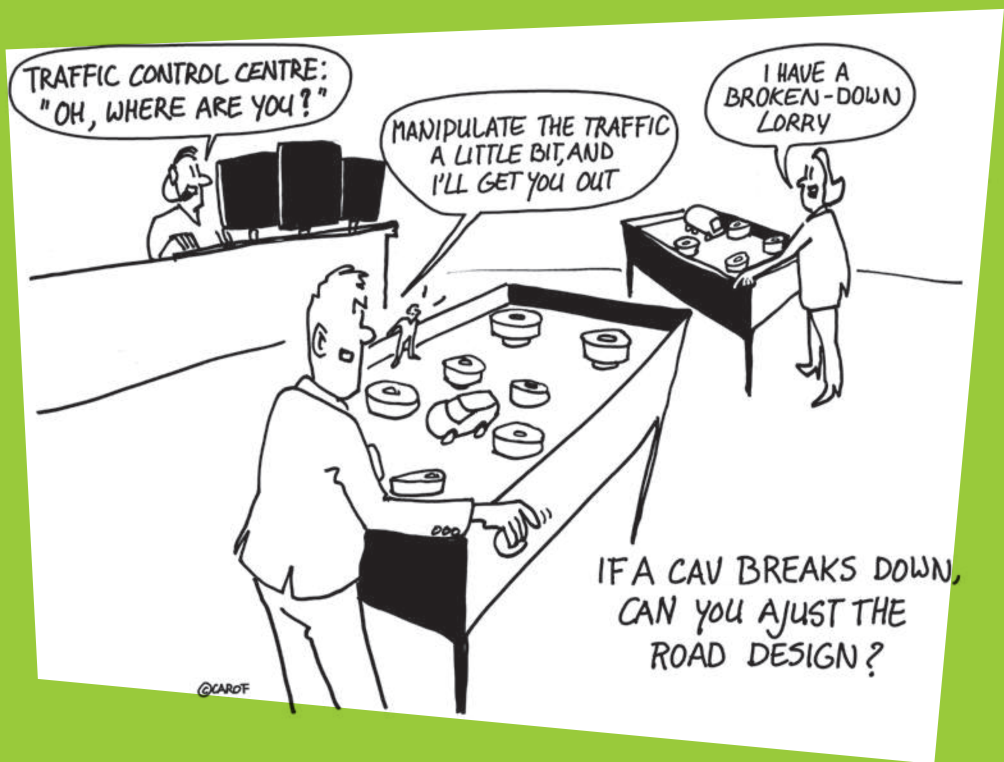
A Day in 2035

Reeva is 32 years old and has been living in the Netherlands for 16 years now. In a media interview, she explains the changes in the field of traffic management over the past 10 years. Reeva is the national coordinator of traffic centers at RWS (Rijkswaterstaat, the Dutch Ministry of Infrastructure and Water Management).

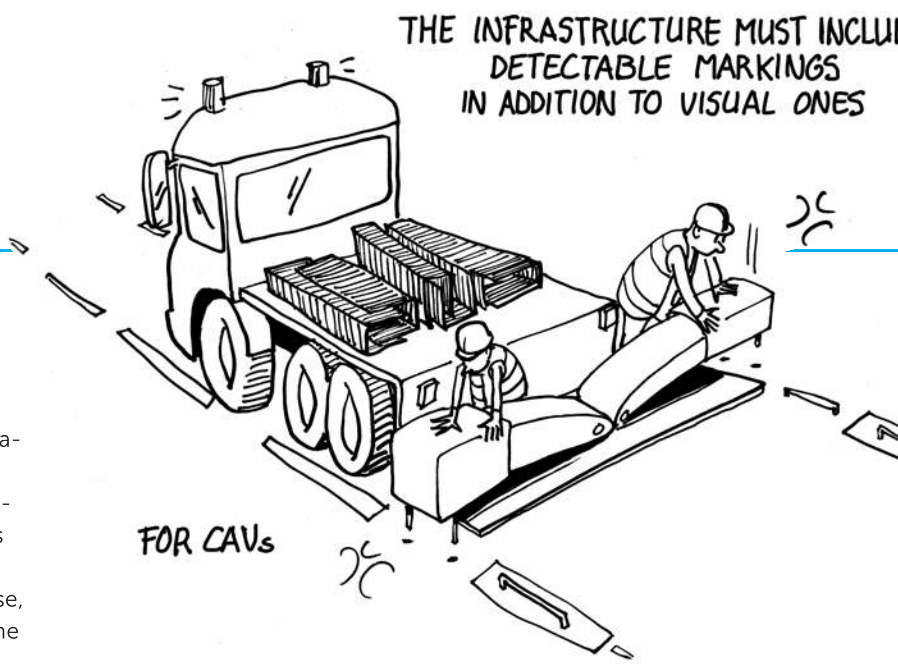
"In recent years, we have strongly focused on phasing out systems located alongside or above the roads. Such systems are costly and also lead to visual clutter," she says. "I experienced the removal of DRIPS (Dynamic Route Information Panels) when I first moved to the Netherlands. There was already sufficient traffic information available through navigation, and almost everyone could access it on the go."

The journalist shifts the focus to the future and asks about her thoughts on the role of traffic centers in the future. Reeva responds enthusiastically, "We are now working on further simplifying the infrastructure and assets. We have significantly reduced road signs, and the classical MTM (Motorway Traffic Management) systems are currently being phased out. The last gantries south of Utrecht and near The Hague will be taken out of service in a few years. Full removal is another question and will require major maintenance efforts. Some gantries will remain on the ring road in Rotterdam to clarify the lanes for specific user groups." The journalist notices that she's avoiding the question and remarks that they were talking about the role of the traffic center. Reeva laughs, "Oh yes, that's right, haha! Well, we are taking steps to introduce digital speed zones. In a while, all vehicles will have real-time speed data, and an increasing number of vehicles are already driving autonomously. Unlike humans, vehicles listen, and now that the data is reliable and real-time, we can gradually implement this. We have also had positive experiences with Artificial Intelligence (AI), and we can be more proactive in our control rather than just reacting to situations, as we used to. Also, the collaboration with service providers has improved significantly."

Later, as Reeva continues her journey to another traffic center, she glances at the old MTM gantries and reflects on how they were controlled when she started at RWS. Although she's running a bit late due to the extended interview, her car suddenly slows down. She quickly asks the dashboard what's happening, and a friendly voice from the speakers responds, "There is slow-moving traffic ahead." There's no option to detour, but she thinks, "See, now I know much earlier than with the gantries that there's a delay, and by slowing down now, I won't end up stuck later."



2030



Progress in use cases:

- All vehicles have ISA (Intelligent Speed Assistance), but no limiting form yet.
- First Automated Transport corridors are operational (hub-to-hub at fixed time windows). Autonomous/teleoperated hub-to-hub transport: autonomous trucks from early adopters operate on a number of advanced corridors where complexity is manageable. In this phase, this high-tech service is still expensive, and the reduction in labor hours is limited.
- More hubs are operational, offering first and last-mile automated transport solutions.
- Fewer motor vehicles are allowed in city centers.
- All new cars are equipped with standard L4-ALKS (Level 4 Automated Lane Keeping System). Governments regulate where these systems can be used, initially on a selective number of motorway sections determined by local authorities that fit within the ALKS guidelines. Also, some suitable N-roads meeting the same characteristics.
- Autonomous transport on segregated (bus) lanes: automatic public transport vehicles operate on some segregated bus lanes, having received type approval within the Implementing Act ADS (Automated Driving Systems). These automated buses are part of the regular public transport system (within a concession).
- Last-mile passenger transportation to and from economically significant locations: automated transport solutions operate in multiple locations in the Netherlands as supplementary transport to the existing public transport network, holding type approval within the Implementing Act ADS (EU-GSR). In various places, autonomous transport is part of the concession, aligning with mobility policies and integral to area development.
- Demand-driven autonomous passenger transportation in sparsely populated/rural areas: automated transport solutions operate in multiple places in the Netherlands as additional transportation to the existing public transport network, holding type approval within the Implementing Act ADS (EU-GSR). In various places, autonomous transport is part of the concession, aligning with mobility policies and integral to area development.

Expansion of digital infrastructure:

- Location determination has significantly improved (via a combination of satellites/GNSS and communication beacons).
- Intelligent Traffic Lights (iTLC) have become the standard.
- Digital twins are available for the main road network. Digital twins of road authorities and private parties are gradually moving closer together.
- Adaptation of Design and Infrastructure / Complexity Reduction / Phasing out Physical Elements:

Special traffic situations on highways are no longer being created, and existing ones are being phased out.

- The operation of automated vehicles in tunnels and other structures has been critically examined, with failure mechanisms identified, and the physical layout and available digital infrastructure of tunnels have been adapted accordingly.
- Possible civil engineering implications of rutting, caused by automated vehicles consistently following the same path within a lane, are being investigated.
- Non-grade-separated intersections with non-motorized traffic are no longer being constructed on rural roads (GOW) outside urban areas, and existing ones are being phased out.
- Spatial layouts in cities are being reevaluated as part of the mobility transition (continuation of Sustainable Urban Mobility Planning - SUMP).
- The first smart roundabouts are in use.
- Planning and design of hubs: significant space is reserved for hubs (for parking or providing services to make the hub attractive, depending on how sharing concepts develop).

- The phasing out of traffic signs and signage has definitively begun, starting with the removal of non-functional signs.
- The phasing out of Dynamic Route Information Panels (DRIPs) has definitively begun in the planning and work processes of road authorities.
- Roadside signs and signage are consistent with the information offered digitally (providing confirmation and trust in the digital information).
- Fewer objects along the road also reduce the need for protective barriers.

Supporting processes:
- Audits conducted according to RISMII (Risk and Safety Management for Intelligent Infrastructure) also consider the safe functioning of ADAS/ADS (Advanced Driver Assistance Systems/Automated Driving Systems) in the assessment.
- EU categorization of roads for route choice and ODD (Operational Design Domain): the road categorization has been updated for automated vehicles, including a specification of the associated service levels ODD-ISAD (Intended Operational Design Domain - Intended Specific Operational Design Domain). Road authorities actively use this in developing network visions.
- A consistent and practical approval framework for automated vehicles has been developed by all involved stakeholders.
- The focus until 2030 is on traffic safety during the implementation and rollout of automated passenger cars in the Netherlands. The country follows international European guidelines, laws, and regulations.

A Day in 2030

Noah is 31 years old and works at a cargo handling company. His tasks involve registering incoming goods and notifying the departure of shipments. While much of this process is automated, some level of manual control is still necessary to verify accuracy and the condition of the goods. His company has been using a shuttle service with automated trucks for over a year now. The production and cargo handling facilities are located near an entrance and exit ramp of a highway, where transportation takes place.

On the highway, the trucks drive fully automated hub-to-hub. However, for the short segments from the hub to the industrial area, the trucks are still manually driven, as these sections are not yet within the Operational Design Domain (ODD) of the automated trucks.

Noah used to be a shuttle-driver on this 8 km route, but he managed to be retrained as a goods receiver. This change has brought him more peace and better working hours. While the self-driving trucks often arrive at night, once they are on the premises, there's no rush to handle the canned vegetables quickly. Still, he starts early in the morning, around 06:15. He checks which trucks have arrived and where they can dock for unloading. While he doesn't have to do the unloading himself, he verifies that the correct goods are delivered and performs random checks to ensure the right labels are used. After all, Albert Heijn doesn't want to receive labels from Jumbo.

Today, he quickly realizes that an entire shipment is missing. On his screen, he can see the positions of all the trucks, and that's how he discovers that one truck is stopped at the side of the road. The service team was alerted earlier and was almost done replacing the tyre on the front axle. Fortunately, everything was handled safely, and the other traffic wasn't affected much. They have an agreed response time with Rijkswaterstaat (the Dutch Ministry of Infrastructure and Water Management) for breakdowns, and it was met today. However, it messes up his schedule, as other trucks with drivers will now have to load at the docks later. Noah decides to have the affected truck dock tonight instead. It'll mean he'll be home half an hour later, but after all, it's still the world of transportation.

2025

Expansion of digital infrastructure:

- Road authorities provide road and traffic-related information (via the RTTI directive) to OEMs (Original Equipment Manufacturers) and service providers. The 2022/23 ITS directive and RTTI serve as a step towards a system that is increasingly prepared for autonomous driving.
- The rollout of the basic network for vehicle-to-road communication starts (e.g., at intersections and traffic lights).
- Further elaboration of digital traffic management has taken place.
- Suppliers and delivery services gain access to zones reserved specifically for them.
- For the required connectivity, intensive work is being done in the coming years on traffic systems (including intelligent traffic signal installations, cameras, roadside stations) and improving the digital infrastructure for the main road network.

Adaptation of design and infrastructure / complexity reduction / phasing out physical elements:

- In the construction, maintenance, and management of road markings and signage, road authorities explicitly consider the functioning of smart vehicles/ADAS (Advanced Driver Assistance Systems).
- The reduction of parking spaces for cars in city centers continues as part of the reevaluation of spatial layouts in cities.
- On the main road network, the phasing out of DRIPs and non-functional TDIs (Traffic Dosage Installations) has progressed from policy to the planning and work processes of road authorities.

Supporting processes:

- Aspects related to the safe and comfortable functioning of ADAS are included in the HWO (Handboek Wegontwerp - Road Design Manual).
- The inclusion of Smart Mobility (regarding automated vehicles) in MIRT (Meerjarenprogramma Infrastructuur, Ruimte en Transport - Multi-Year Program for Infrastructure, Spatial Planning, and Transport) trajectories begins.
- MaaS (Mobility as a Service) acts as a preparatory platform for multi-modal chain travel with a single payment system.
- A framework for ALKS (Automated Lane Keeping System) approval on Dutch roads has been developed by joint road authorities, aligned with the EU General Safety Regulation (GSR) and Implementing Act ADS.

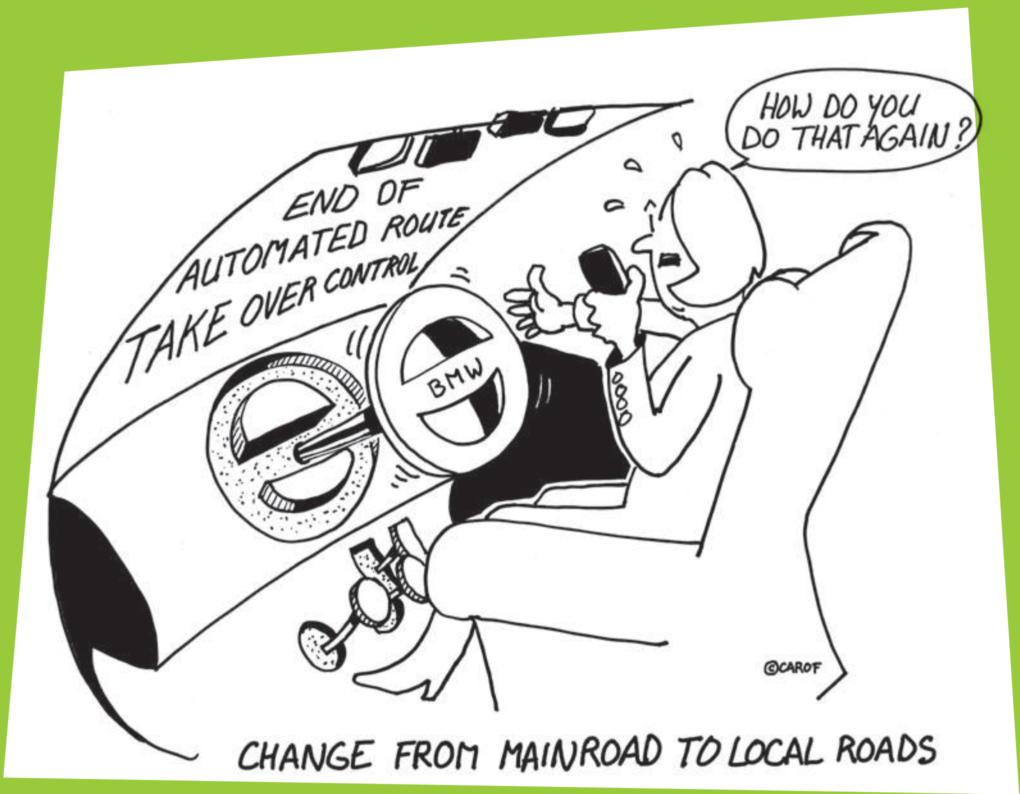
A Day in 2025

Annika is 25 years old and recently started working as a traffic engineer at the province. Her higher professional education in traffic engineering was somewhat different from that of her older colleagues. Annika is better at bridging the gap between data and traffic engineering. She can analyze data and information with a traffic engineering perspective and approach traffic engineering problems with data expertise.

When reviewing designs, she strictly adheres to the new road design manual. This manual also includes recommendations for road design and smart vehicles, and Annika is keen on making designs as future-proof as possible. The province has a 12-kilometer stretch of road that is a 2x2 non-grade-separated configuration. There are requests from car manufacturers to use ALKS on this type of road, and within a few years, the first vehicles with Level 4 functionalities will be allowed to use this stretch. On Monday morning, Annika is already at the office early when she reads an email stating that the stretch might be dropped from consideration. Between the 12-kilometer road of the province and the highway, there is an intersection with traffic lights. That point falls outside the ODD (Operational Design Domain) of this approval, and her colleague points out that for a responsible application of ALKS functionality, stretches should be longer than 23 kilometers to limit the number of human takeovers.

In regional meetings, Annika makes it clear that the intersection is due for revision. It involves only conflicts between motor vehicles, and she wants the intersection to be non-grade-separated in the next reconstruction. However, due to the relatively high costs, her proposal meets resistance. Now, along with her colleagues, she is considering the idea of making non-turning traffic at traffic lights autonomous and investigating what is needed to achieve that.

Through this incident, Annika is convinced that infrastructure should be simpler, but it is essential to keep modes separated as much as possible and bring them together where multimodal exchange is logical or desirable.



4 Conclusions

The vision for 2060
As our ultimate goal for the future, we envision a spot on the horizon in 2060 where technological advancements have led to a traffic and transportation system that significantly contributes to the quality of life and the environment. Automated vehicles, connectivity, and digitalization play a crucial role in achieving this vision. However, the central focus is not solely on technology but on understanding human needs and the surrounding environment. Automated transport will contribute to societal objectives in areas such as traffic safety, social security, livability, health, accessibility, and comfort, as an integral part of a multimodal traffic and transportation system that is accessible to everyone.

All newly registered vehicles are connected and equipped with automation, albeit at different levels. Most safety and efficiency functions have been taken over by the vehicle from the human driver. There are various applications of automated transport, catering to both individual and collective passenger transport as well as transport and logistics. On the main road network, all applications are active, and automated vehicles are the norm and standard (non-automated driving is allowed under specific conditions). The underlying road network also supports automated transport, but the mix of road users with varying levels of automation (from 'manual' to 'fully automated') determines the design of the traffic system. In residential areas, roads are primarily designed with the human road user in mind due to the complexity for AVs (Automated Vehicles) and from a social perspective. As a result, private car parking space is no longer necessary in residential streets, and a switch from active modes of transportation (walking, cycling) to a motorized mode can be reached within 5-10 minutes.

Implications for physical and digital infrastructure
to realize the vision of 2060, the design and layout of roads will inherently consider automated vehicles. There has been a shift from primarily considering human drivers to focusing on the specifications of automated vehicles (on routes where AVs are normative) or the combination of AVs and human drivers (on routes where manual driving is allowed).

The fundamental principle for infrastructure development is that the physical infrastructure does not require major modifications, while the digital infrastructure is highly developed. Design and layout of the infrastructure are based on core principles: reducing complexity and increasing uniformity and clarity, with special attention to road quality through management and maintenance. Essentially, this is a continuation and updating of the principles for Sustainable Safe Road Design, which have been applied since the 1990s. The qualitative boost to the traffic system is accompanied by cost reductions as unnecessary elements no longer need maintenance, and routine management and maintenance can be conducted efficiently and proactively using asset information provided by CAVs (Connected and Automated Vehicles).

Achieving the vision of 2060 entails a step-by-step reduction of complexity and an increase in uniformity. This involves phasing out physical elements/special features that are no longer functional (decluttering the traffic environment), gradual development of the digital infrastructure (with connectivity, cooperative systems, localization, and data as key aspects), and standardization of both physical and digital elements. The physical and digital infrastructure function as one system, supporting each other and fully aligned. The physical infrastructure is complemented by a complete digital representation (twin) as the basis for ODD (Operational Design Domain) management (providing access for automated vehicles according to the available service level from the physical and digital infrastructure - ISAD), traffic management, and asset management (optimal utilization of available road capacity). HD-maps serve as the interface for vehicles, and connectivity (V2X) enables the appropriate information to be available in vehicles and for all road users at the right moment.

By employing the future backcasting approach in this paper, we have reasoned backward from 2060 to the present, providing an understanding of how the gradual development can be realized to achieve the goals in 2060 and prevent disinvestments along the way. The accompanying timeline is explained below, and it is based on insights from expert interviews we conducted and aligned with global perspectives from key publications in the literature[3].

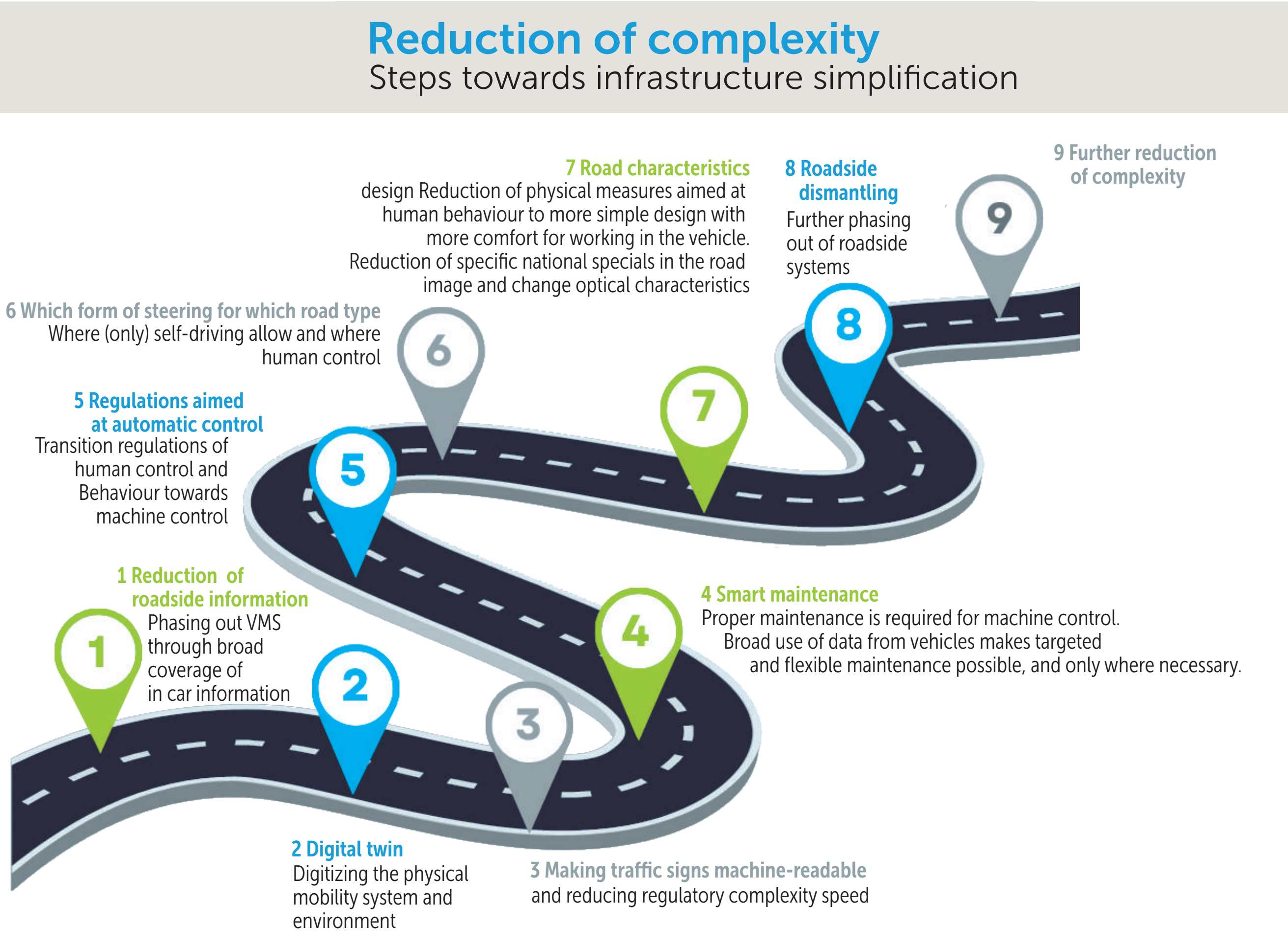


Figure 8. Illustrates the steps from the future to the present (from step 9 to step 1), presenting a potential backcasting path for reducing complexity. This path can be followed from the present, starting at step 1, but the further away the step, the greater the uncertainty.

3 With the ERTRAC roadmap (2022), the Vision on Automated Driving, Rijkswaterstaat (2021), and the CAV Policy Vision from the Joining of Forces (2023) as good references of anticipated implications of AV on the (inter)national main road network and the roll-out of use cases over a larger part of the network.

9 Further reduction of complexity

Further reduction of complexity and, where possible, disentangling traffic flows.

To achieve increased safety through automatic driving and a different use of space and capacity, it is necessary to minimize complexity in the environment. Smart vehicles demand a simple layout (homogeneous and clear road design). This allows for greater safety gains and ensures a comfortable ride, enabling travelers to use their time for work, eating, or relaxation instead of driving.

There is a clear separation of ODDs (Operational Design Domains) based on the function of automatic driving, mixed traffic, and human driving. The choice of where to allow (only) automatic transportation determines the design elements. On these routes on the main road network , uniformity has been increased (with EU-guided basic characteristics). The separation of conflicting traffic streams and simplification of conflicts have largely been completed. Challenging maneuvers, such as left turns, are minimized, as well as conflicts with other modes of transportation (active and motorized modes are disentangled), and special features have been phased out. On the underlying road network, conflicts between motorized and active modes continue to exist at many locations. Intersections are primarily designed as roundabouts (argument: reducing complexity and decluttering the infrastructure). Speed humps and other measures such as road narrowing are no longer applied. In residential areas, roads are primarily designed with human road users in mind due to complexity for AVs and from a social perspective. As a result, private car parking space is no longer necessary in residential streets.

No concessions have been made to the safety level of roads, and there is no drastic resizing of road profiles. Accidents still occur to some extent, and an obstacle-free zone is necessary for vehicles to safely bring themselves to a stop when needed. Additionally, some correction for strong winds will still be necessary to compensate for lateral movements caused by larger vehicles. Sufficient space should be integrated into transition areas for the shift from automated to manual driving.

8 Reduction of roadside elements

Further reduction of roadside systems.

The situation has been achieved where roadside systems, signage, and public lighting have been gradually reduced on roads where only automated driving is allowed. There are fewer traffic lights on the main road network due to conflict reduction at intersections and junctions, with in-car traffic regulation and signaling becoming more prevalent. The development of connectivity and cooperative systems plays a significant role in this (V2X communication between road users). The decluttering of the traffic environment is largely complete, and the visual quality of the infrastructure has greatly improved due to the removal of most complexity. However, it is essential to remain attentive to situations where manual driving is still necessary, such as during communication outages or exceptional weather conditions.

7 Road characteristics and design

Phasing out physical measures aimed at human behavior and transitioning to simpler design with increased comfort for working in the vehicle. Reduction of special features in the road design and optical features targeted at human behavior, shifting towards machine control.

Significant efforts have been made to reduce or modify Dutch road network's special features that impede automated vehicle functioning (such as tapers, managed lanes, and specific road markings on roads like ETW 60) in good alignment with developments in the automotive industry. The goal is to create a homogeneous and clear road design, minimizing speed and course changes as much as possible. Unlike human driving, machine control does not benefit from optical narrowing and structural measures like speed bumps and road narrowing to maintain a safe speed. In fact, speed can be dynamically controlled through traffic management with speed windows based on current conditions (e.g., slippery roads, visibility, traffic density, or societal factors). This increased comfort allows travelers to use their travel time for other activities (working, eating, or relaxing) instead of driving. High speeds become less relevant as travel time is perceived differently.

6 Type of control for each operational design domain (ODD)

Determining where to allow automated control and where to permit human driving.

A clear understanding of where to allow different levels of automation serves as the foundation for designing the specific ODDs, considering the level of service from the infrastructure and its associated physical and digital elements. Reducing complexity and subsequently simplifying or phasing out specific physical elements, making road construction and maintenance less expensive, starts with making precise choices about what is allowed where. The increase in automated driving on the main road network has led to a shift in the thinking process from where to permit automatic control to where to continue allowing human control and why.

5 Regulation focused on automated control

Transitional regulation from human control and behavior to machine control.

For widespread adoption of automated driving, regulations must be supportive and aligned with the specifications and perspectives of automated vehicles. This includes developing rules for using infrastructure and making traffic and access rules available digitally.

4 Smart maintenance

Smart maintenance is necessary for machine control. Extensive use of data from vehicles enables targeted and flexible maintenance, only where necessary.

Maintenance contracts can increasingly rely on data from vehicles. Maintenance should occur where vehicles indicate that they cannot read the environment (anymore). There are significant opportunities for cost reduction and preventing disruptions by intervening only where necessary. A better balance between preventive maintenance (expected lifespan) and reactive maintenance (actual lifespan) must be achieved. Data from vehicles can also be used to monitor traffic safety policies in terms of road design quality and traffic behavior (e.g., speed, braking movements, etc.).

3 Machine-readable traffic signs

Making road signs and markings machine-readable and simplifying speed regulations.

In addition to making data available and interpretable, vehicles (and humans) must be able to understand the environment themselves. It is essential that signs and characteristics are easily readable by machines. Certain signs, such as combined signs and specific speed regulations, are currently not machine-readable. Simplifying the speed landscape helps reduce the number of different, time and situation-dependent speed limits, thereby simplifying digitalization. Clear and detectable road markings, visible under various light and weather conditions, and easily interpretable markings improve the function of (automatic) Lane Keeping Systems.

2 Digital twin

Digitalizing the physical mobility system and environment.

To make progress in automated driving, the digital infrastructure must match the physical infrastructure. The digital twin of assets must be well-organized. This applies not only to static but also to dynamic (real-time) and temporary aspects (see ITS directive/RTTI). It involves information about road design and layout, signage, and also geofencing and prohibitions. At this stage, this is not only important for the further development of autonomous driving but also for human interpretation and support via ADAS (Advanced Driver Assistance Systems).

1 Reduction of roadside information

Phasing out Variable Message Signs (VMS) due to comprehensive in-car information.

Since almost everyone can now access accurate information about current road conditions through navigation services, Variable Message Signs and similar roadside information can be phased out. The focus shifts towards providing digital input of critical information through in-car systems, including route choices that take policy aspects into account within navigation (RTTI, VM-IVRA). Efforts are also made towards the secure transfer of in-car information by standardizing texts and avoiding excessive warnings.

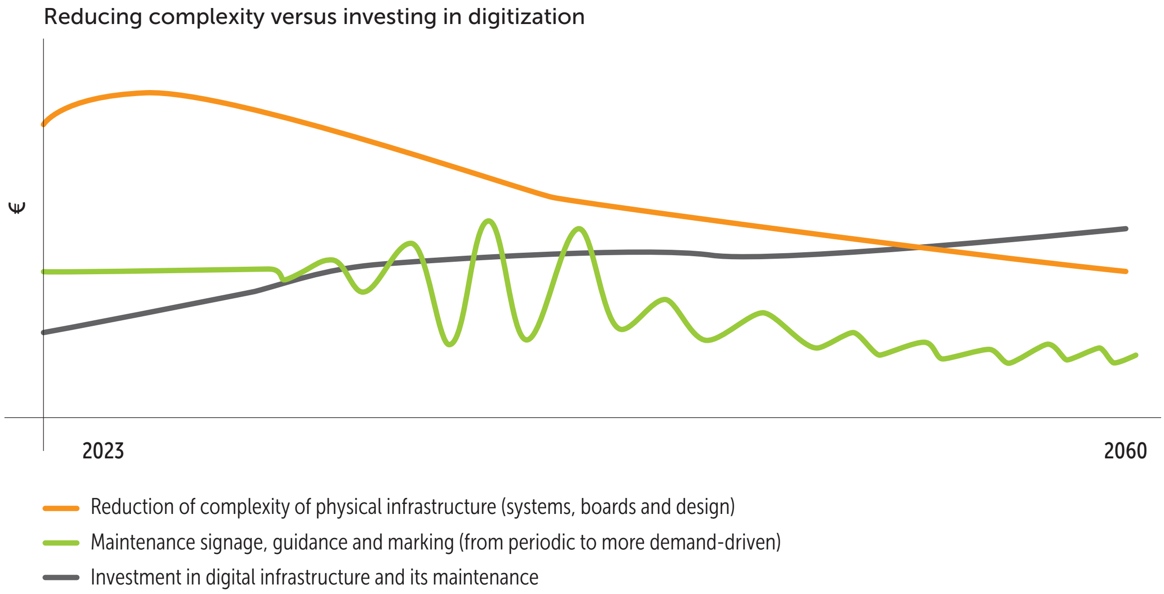


Figure 9. Changing roles and intervals: the investment in digital infrastructure and data will increase even further, the costs of physical infrastructure will decrease due to austerity and more reactive maintenance, focused on the function of vehicles that indicate whether the observation is still sufficient.

Impression of the investment line

Through the timeline, we foresee that the road does not need to be extensively modified for automated vehicles. Instead, we anticipate a direction of simplifying the physical infrastructure and expanding the digital aspect. Dutch road features will disappear, especially in areas where we focus on automated driving. This will have a cost-saving effect and align with a uniform design for automated driving at the EU level. New assets that may be needed, such as smart roundabouts, will be gradually introduced, spreading the required investments over time.

Figure 9 illustrates this concept: a reduction of complexity in the physical infrastructure combined with an investment in digitalization. More and more digital: investments in expanding digital elements will pay off as less investment is needed in physical infrastructure (assets). This opens up cost-saving opportunities for efficient maintenance, driven more by data from connected vehicles and less on a time-based interval (the focus is on the readability and functioning of functions as the central trigger).

The figure outlines a general roadmap for a future-proof development of road design, supporting the potential of automated traffic and transportation, as well as the necessary developmental steps. It starts with getting the basics in order, through the fundamental principles: reducing complexity, increasing uniformity, and clarity. Initially, this applies to the physical aspect to facilitate the functioning of smart, automated vehicles according to their Operational Design Domains (ODD). Simultaneously, digitalization follows, partly in parallel, while avoiding significant efforts in digital information/twin for roads that still have many physical complexities. These complexities may lead to ADAS/ADS encountering many gaps in their ODD, resulting in disengagement and transitional situations (uncomfortable and potentially unsafe). The focus of digitalization should be on routes/sections that are already largely well-equipped in terms of physical design. Digitalization should be used as a complement to the physical infrastructure[4]. Based on this reasoning, it is also essential to work towards simplifying the speed landscape to support the digitalization of information on speed limits.

Further considerations from the development of the mobility system (mobility transition)

The description of the timeline and the investment line provide an overview of the developmental steps for the coming decades, from the perspective of infrastructure for the deployment of automated vehicles. However, it is essential to zoom out and see the position of AV infrastructure developments in the broader context of the evolving mobility system. Figure 10 provides an impression of this.

4 See PIARC Smart Road Classification document (2023).

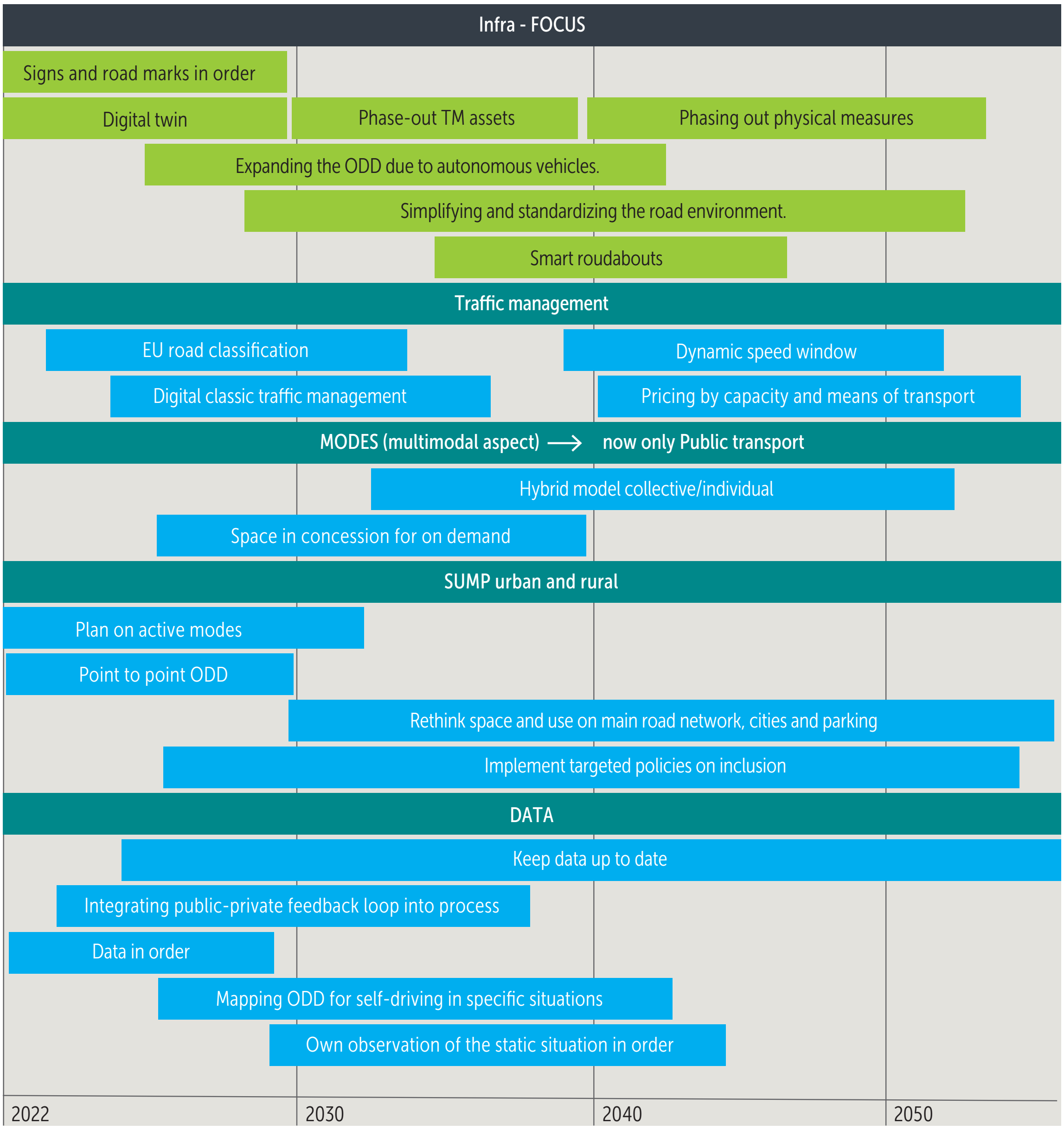


Figure 10. Overall in time (below) we see the items related to infrastructure that are relevant to the transition, with the broader picture below.

From the figure, several aspects arise that require further development, including the following:

- Vision of where automated vehicles are useful and desirable (and where not), in connection with other modes of transportation, also as part of shared mobility concepts.
- Developments are characterized by the search for a balance between what is already technically possible and where the main challenges, needs, and revenue models lie (balancing societal value case and commercial economic business case).
- The development of infrastructure should run parallel to the admission of automated vehicles to the road network or specific road types/zones within it.
- Road categorization based on ODD-ISAD service levels. Determining where manual driving is still permitted.
- Further development of rules for the use of infrastructure (coding and managing curbs/urban space management) and making them digitally available. For example, disallowing long-term parking on AV routes (in city centers).
- Developing a data vision (identifying the data needed by road authorities and vehicle manufacturers, and what is available) and establishing a legal framework for data collection and exchange. Coordination between road authorities, manufacturers, service providers, and map makers regarding a common understanding of digital twins.

Part 2

5 From focusing on the human driver to focusing on the automated vehicle in road design and infrastructure

Our mobility, especially road traffic, is undergoing an interesting transition with significant changes. We are moving from a period in which the driver of a car had to gather and interpret all the information and control the vehicle manually, to a period where the car can operate fully automatically under certain conditions. In between lies a period of at least several decades, during which the car, with its ADAS applications, progressively takes over more functions and increasingly supports the driver in safely executing their driving task. There are shifts occurring in the traditional relationship between humans, vehicles, and the roads on which our traffic system has been built over the past decades.

In Part 2 of this whitepaper, we will delve further into this topic as background information to the images presented in Part 1. We will focus on the position of automated vehicles in the broader mobility transition, the changing relationship between humans, vehicles, and roads for automated traffic, and developments that already exist and are foreseen in the field of automatic traffic and transportation. All of this will be viewed in the perspective of developing physical and digital infrastructure to enable, support, and accelerate the responsible introduction of automatic vehicles into the traffic system, especially where the societal and economic value is high.

5.1 Technological developments as a contribution to mobility transition and societal goals

The developments in automated traffic and transportation are part of the broader mobility transition we are currently experiencing. Within this transition, there is a growing awareness that we need to reorganize mobility and the space required for it to improve the quality of our living environment. This is evident in cities, which are becoming increasingly crowded in limited space, as well as in more rural areas where transportation poverty is a looming issue. Changes are necessary in the short term and especially for future generations if we are to achieve climate goals and prioritize the quality of life through a safe, clean, and pleasant living environment.

"Technology is not the central focus here, but rather the human with their needs."

Following this sequence of reasoning, technological developments can contribute significantly to the four dimensions of Broad Prosperity (in Dutch: Brede Welvaart) concerning mobility (as published in 2022 by the Netherlands Environmental Assessment Agency (PBL)): Environment, Accessibility, Health, and Safety. Advancements in automated vehicles will progress alongside sustainable spatial usage, sustainable energy generation and usage, efforts to counter overconsumption, increasing inclusivity, and promoting active modes of transport (cycling and walking) through a system change initiated by the Mobility Transition. Incrementally, initiatives are being taken to shape this system change, including from:
1. *Personalized motorized transport*, 2. *Collective transportation (public transport)*, and 3. *The transportation sector (logistics)*.

Through a gradual rollout of use cases related to these modalities, automated traffic and transportation can contribute to societal challenges concerning the quality of our living environment and sustainable, safe, efficient, and inclusive mobility.

Of course, not all recent developments have been equally successful, and there are still various challenges to overcome in aligning societal value cases and private business cases for the large-scale implementation of automated vehicles. However, developments are continuously progressing, and the benefits will be reaped sooner or later. A step-by-step and adaptive approach is necessary for a responsible and safe introduction of automated traffic and transportation, providing sufficient room for learning and evaluation, accelerating positive aspects, and managing risks.

"Self-driving is certainly not a futile endeavor. After all, nearly all accidents are caused by human errors."

"So, if technology can eliminate human errors, then it can certainly make a significant contribution to reducing the number of traffic fatalities. A self-driving system is never tired, never drives under the influence of four beers, never looks at a phone, and never speeds."

5.2 The changing human-vehicle-road relationship

In traffic engineering, planning, and regulations, we have been accustomed to focusing on humans as the drivers of vehicles. However, in 2023, we are witnessing the first signs of a gradual and fundamental shift in this dynamic. It is still uncertain how far this shift will go, but the role of the human driver will remain for a long time. Consider hobby drivers, motorcyclists, construction vans, machinery, and more. Nonetheless, as vehicles take over from humans, we need to approach infrastructure differently.

If we consider this perspective from a different angle, we quickly realize that digitalization is a key factor leading to self-driving capabilities. Systems like ISA partly rely on data, but looking into the future, something like ISA seems to be a step towards digitally imposing variable speed limits based on conditions such as traffic density and road conditions. (A)LKS in combination with ACC forms the foundation for level 4 autonomous driving and will undoubtedly continue to evolve in the future. Route selection, which we are now incorporating more policy-wise into navigation under the RTTI regulation, will eventually result in autonomous vehicle route choices, with adherence becoming increasingly important.

With autonomous driving, the desired behavior of a vehicle becomes more achievable. Dynamic Traffic Management (DVM) assets and infrastructure measures become less relevant as a result. Even though manually driven vehicles will still exist for a considerable period ahead, when the density of self-driving vehicles becomes significant, exceeding speed limits becomes challenging. Moreover, measures around access to specific areas for certain vehicles will lead to route choices aligning more with societal preferences.

Over time, the role of ADAS in supporting drivers will shift towards automatic execution by the vehicle itself, making the desired behavior more attainable. As a result, physical elements can gradually be phased out (depending on the vehicle type, this may be closer or farther away). The keyword is connectivity. All information reaches the vehicle through a combination of its own perception, data, and centralized control.

This transition implies that the development of the road network and road design must increasingly consider the interaction between smart vehicles and the traffic environment. In addition to information about fellow road users, this involves information about the physical infrastructure (road design, signage) and data from the digital infrastructure (permissions, traffic and route information). The digital infrastructure will progressively function more as a digital twin of the physical infrastructure, with HD maps serving as the interface towards the vehicle.

The infrastructure has become complex to support human behavior and reduce undesirable actions. Additionally, we observe that warning the driver is more complex than alerting a vehicle (correct timing and explanations are often necessary). As automated driving entails controllable behavior (following clear commands), smart vehicles require less complexity. Generally, what is challenging for humans to perceive or understand is also challenging for vehicles. Simplification, standardization, recognizability, etc., benefit both human and machine control. Even if autonomous driving never materializes, investments in uniformity and clarity can still be justified and considered as no-regret measures.

The transition period from a situation where the driver of a car must gather, interpret, and control all information to a scenario where the car might function fully autonomously is gradual. The shift in the traditional human-vehicle-road relationship (from a focus on the driver to a focus on the vehicle) involves the gradual integration of technology into the vehicle fleet. There will be a prolonged existence of a hybrid mix of vehicles with varying levels of task automation.

Note: A focus on the vehicle instead of the driver does not diminish the central role of humans. This change must contribute to higher societal goals that benefit people (in harmony with the planet) and align with human acceptance. In the third P (Profit), provisions must be made to initiate and sustain developments, with a balanced public-private approach between societal value cases and economic business cases.

Is the necessary information available for the vehicle to function safely and comfortably, and is it also present in the vehicle? Can sensors perceive it, does the required communication work, and is there no contradictory or non-unambiguous, ambiguous, or unauthorized information?

The diagram illustrates how ADAS applications can directly and indirectly influence the operational driving task (speed and course) and, through proper interaction with the infrastructure and the driver, can make a significant contribution to traffic safety. However, if the (including digital) information from the infrastructure or the environment is not processed correctly or is misused by the ADAS application, these functionalities can also lead to unsafe situations. This applies even more strongly to vehicles with a higher degree of automation (ADS).

People with disabilities have a need for the human aspect of society but also see the potential of autonomy and mobility, while recognizing the importance of social behavior and communication among road users in the environment. Autonomous driving and the social aspects of traffic participation are still finding their synergy.

5.3 Responsible introduction of automated traffic and transport

For a responsible introduction of ADAS and more advanced forms of automated vehicles into the mobility system, a good interplay between humans, vehicles, and infrastructure is crucial:

- Key factors at the *human level* involve striking a good balance between societal value cases and economic business cases, preceded by aligning with human needs, support, and acceptance among users of the living environment (as travelers or residents).
- Key factors at the *vehicle level* include the development of new tests and approval procedures, as well as advancements in driver education and licensing. From a broader perspective within the mobility system, we see significant opportunities for automated vehicles as an integral part of a multimodal traffic and transportation system. This requires a vision of where automated vehicles are useful, desired, and allowed in connection with other modes.
- Key factors at the *infrastructure level* concern the quality of physical and digital infrastructure. To function safely and comfortably, automated vehicles require certain quality levels in terms of road design and layout and the availability of digital support (reliable data, communication, and positioning technology). The development of infrastructure must be synchronized with the admission of automated vehicles to the road network or specific road types/zones[5].

An important starting point for the responsible introduction of automated vehicles is to ensure that technology remains at the service of humans (addressing needs and acceptance). Additionally, taking an integrated approach to system change is crucial. An integrated perspective and vision help to make the right investments and recognize when adjustments are needed in a timely manner. Vision and an open-minded approach also assist in leveraging the strengths of different parties involved. For governments/road authorities, this can be challenging, as digitalization and technological developments progress rapidly (with short life cycles), while infrastructure assets have much longer life cycles. Therefore, it is essential to explore development paths for a future-proof evolution of the road network and road design. This ensures a clear perspective, attractive goals to work towards, and the achievement of urgent societal objectives through a responsible introduction of automated vehicles in the most efficient way possible.

5.4 Current state: increase in adas and gradual introduction of ads

To gain a better understanding of possible development paths for vehicle automation in the future, this section describes the following points:

- The current situation regarding automated vehicles.
- Foreseen developments.
- Dilemmas surrounding the further introduction of automated vehicles.

The current situation:
In an international/EU perspective and considering the paths taken in the past:

- *Advanced Driver Assistance Systems (ADAS):*
  The short-term relevance of automated vehicles lies primarily in the added value of ADAS. In the coming years, there will be a steady increase in ADAS in the vehicle fleet. According to the EU General Safety Regulation (GSR), vehicles must be equipped with certain ADAS (e.g., ISA, Lane Keeping, and AEBS) starting from 2022/2024. To promote the safe and proper use of ADAS, the ADAS Alliance was established in the Netherlands (since 2019). The incorporation of ADAS is also taking place in trucks (e.g., emergency braking system, active Lane Keeping, ACC, and blind-spot assistant). To realize the added value of ADAS, it is essential for ADAS to function well in various situations and meet the needs of end-users.

- *Introduction of further automation (level 3 - alks):*
  The gradual introduction of systems with advanced automation has been initiated based on the recently revised European General Safety Regulation (GSR) and Implementing Act. In some time, it will be possible to apply for European type approvals for automated vehicles, but member states will still have the authority to set conditions for the places where such vehicles are allowed to operate. Applications for the approval of vehicles with ALKS (Level 3) are expected in the near future.

5 When vehicles are approved for use on the Dutch road network, it must be clear where they can/cannot operate automatically. This point is currently relevant for ALKS.

Currently, the Ministry and RDW (Netherlands Vehicle Authority) are preparing recommendations regarding the approval of ALKS as part of the implementation of European rules in Dutch regulations. ALKS is currently intended only for highways. Coordination between governments and road authorities takes place within the Smart Mobility Coalition (Working Group CAV) and the recently installed National Taskforce ADS (initiated by the Ministry of Infrastructure and Water Management, Rijkswaterstaat, and RDW).

- *Platooning:*
  The practical implementation of platooning (trucks) is currently on hold, and there is uncertainty about its future. However, the development steps taken in recent years are considered significant precursors to automation in the transport sector. The efforts required to organize platooning seem to be the main obstacle for a possible restart. For the logistics business case, the main advantage lies in eliminating the need for a driver in an automatically driven vehicle. The additional benefit of platooning, i.e., reduced fuel consumption, is currently estimated to be less significant.

- *Automated public transport:*
  An agenda for automated public transport has been developed as part of the Smart Mobility Coalition. The aim is to fulfill the vision that automated passenger transport will be an integral part of a demand-driven and finely meshed (collective) transport system by 2040, from the perspective of collaborating governments, research institutions, and public transport companies. The foundation for this agenda is the Roadmap for Self-Driving Shuttles 2030, in which first and last-mile passenger transport is seen as a promising application with multiple potential implementation areas spread across the country (province of North Netherlands, South Holland, and North Brabant).

5.5 What developments and dilemmas lie ahead?

The following development paths for automated vehicles (AVs) are emerging:

1 **OEMs focus on the further development of ADAS (Level 2) rather than introducing fully autonomous vehicles (Level 4).**
  OEMs are essentially reverting to the development path they have been pursuing since the 1990s, starting with the introduction of features like ACC. The hype of rapidly introducing fully self-driving vehicles to the market has been somewhat tempered. Several underlying reasons can be identified for this shift in direction:
  - Broader developments in the automotive industry: The sales of new vehicles and the traditional revenue models are under pressure. Manufacturers are investing heavily in electrifying the vehicle fleet and exploring mobility services as new sources of income. Electric shared vehicles, in particular, have been associated with the idea of making them autonomous. Over the past years, various manufacturers have invested tens of billions of euros in autonomous driving technology. However, it has become evident that the technology requires more time to mature than initially anticipated, and the demand for shared vehicles is still limited.
  - Awareness during self-driving vehicle pilots: The realization that humans are still needed as backup in many situations when the automated system fails has grown during self-driving vehicle pilots. As a result, the focus has shifted towards designing systems that support human drivers as effectively as possible, providing services that meet human needs.

"The development path aims to gradually progress from further support in driving tasks to vehicles that can perform more tasks autonomously, rather than introducing fully autonomous vehicles suddenly into the traffic system."

  - OEMs will not develop based on the possibilities in one or two countries but on the "highest common denominator." Although the Netherlands can play a leading role by offering more functionalities earlier (e.g., through digital road infrastructure), this will only become the norm if there is a clear vision that supports it.
  - The expectation is that cars will initially drive with higher levels of automation on highways and in traffic congestion (personalized motorized transport). Human drivers welcome support on long, monotonous stretches of highways and dislike driving in traffic congestion. However, in urban areas, especially in busy city centers, there is little demand from users for widespread automation. Automatic vehicles struggle to navigate narrow roads with a lot of interaction with pedestrians and cyclists who flexibly interpret traffic rules, resulting in safety issues. Additionally, there is no viable business model for the significant investments required for automation in such complex urban environments.

- Specific applications for automated vehicles in residential areas might be more promising. Examples include automated parking lot searches or automatic travel from a parking lot outside a residential area to the doorstep (e.g., Buurautonoom initiative). Another example is a self-driving shared vehicle that picks up people within a residential area (city center, residential neighborhood, or business park) and transports them to a city hub within a distance of about 0.5 - 2 km.

2 **Developments in automated driving technology are attracting attention from companies outside the automotive industry.**
Notably, companies like Google's sister company Waymo are investing in L3 and potentially supplying OEMs in the future or being acquired by them. Robotaxis in places like San Francisco have gained significant media attention. These are conventional passenger car models (no futuristic design) equipped with extensive technology, making them expensive. They operate within a specific area (geofence), during specific time slots (e.g., evenings, to avoid competing with other transport services like public transport), and avoid operating in adverse weather conditions.

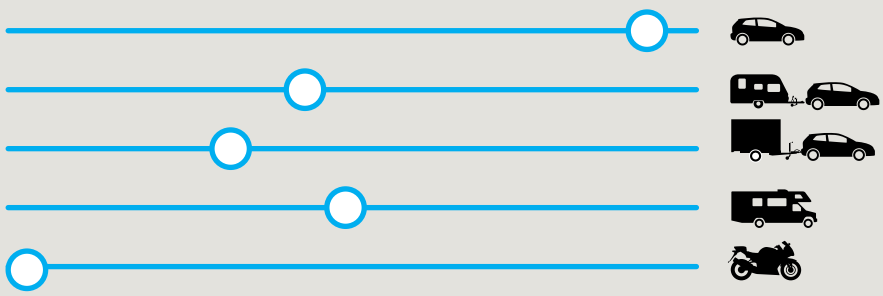
3 **Focus on transport and logistics**
There is a greater focus on the development of automated trucks rather than connected trucks or platooning. Automation will be primarily implemented for point-to-point transport on fixed routes. Additionally, there is a concept of automatic transfer of trailers from the end point of a route to the loading/unloading location using a "smart dolly." The European MODI project and the CCAM ambition in the Netherlands aim to implement automatic transport via TEN-T corridors between 2025 and 2030.

Foreseen automation profiles
there will be a long period during which human drivers will continue to operate vehicles. This can be driven by various factors:

- Driving is enjoyable:
  - There will be a group of people who prefer to drive a vehicle themselves.
- Driving has an image:
  - For instance, motorcyclists are unlikely to switch to self-driving motorcycles (even Intelligent Speed Adaptation - ISA is not mandatory for motorcycles).
- Autonomous driving is too complicated:
  - Vehicles will not take over driving in all situations. There are questions about whether it is desirable to allow autonomous transport everywhere (e.g., robotizing residential areas) and whether it will be possible for all vehicle categories. Special transport, for example, might remain a challenge. The costs of automation will be high, while such vehicle types are relatively rare on the roads.
- Work equipment:
  - Vehicles should not only be able to drive themselves but also take over the work function..

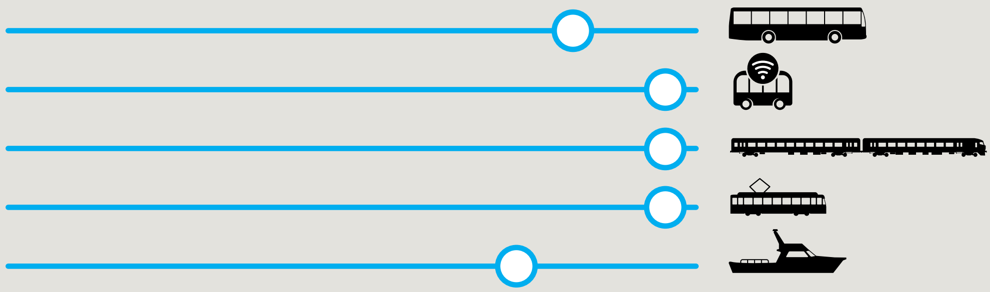
The potential for development varies for different modes of transportation:

Individual motorized mobility



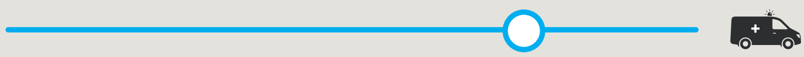
The development potential for passenger cars is high. However, passenger cars with trailers or caravans may present challenges unless automated vehicles become proficient at reversing, which users might desire. Self-driving motorcycles and classic car owners are unlikely to be interested in autonomous driving, while the prospects for campers remain uncertain.

Public mobility and transport



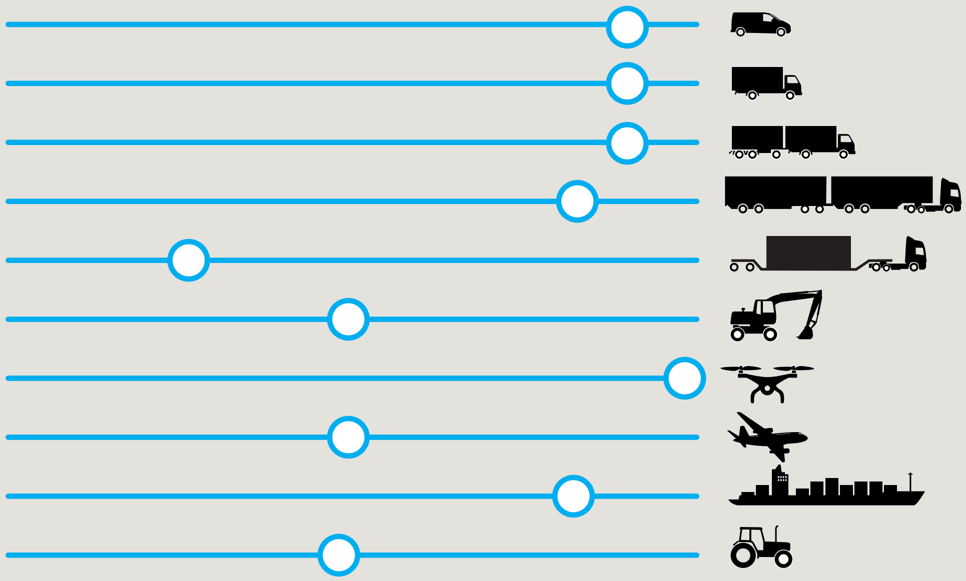
The potential for automated passenger transport seems high, provided there is societal acceptance. The main challenge lies in ensuring social safety. For buses, the potential depends on the Operational Design Domain (ODD) and may remain complex in intricate situations. In the maritime sector, the potential for automation also appears high, but it may be less for ferry crossings, unless proper safety measures are put in place for river crossings.

Emergency and rescue services



For emergency and rescue services, autonomous vehicles (AVs) could potentially be a solution to address personnel shortages and reduce associated costs. However, the main concern is how AVs will perform in urgent tasks that require high speeds.

Transport and logistics



The potential for development in the transport and logistics sector is high, with the exception of exceptional transportation, which can be quite costly to automate effectively. In the aviation industry, human backup will likely remain desirable for safety and public acceptance, although most of the journey has been autonomous for years. For work and agricultural vehicles, the question is how important driving is compared to the tasks these vehicles perform, and whether such work should and can be automated.

Dilemmas in the further development and implementation of AVs:

From the perspective of users (humans) - acceptance, support:

- AVs may lead to increased car usage and longer travel times, as people can use their travel time differently and find driving in congested traffic less bothersome. This could potentially lead to a decline in the use of public transport.
- Human drivers can avoid errors that AVs might not anticipate, and they can adapt to traffic situations flexibly through social interactions and communication.
- Users want the option to choose between manual and automatic driving. Access to certain roads or routes may require automated driving mode, which could affect the overall societal goals of AVs and impact their acceptance.

Legal and ethical issues:

- The move towards fully self-driving cars raises legal and ethical questions. Plans for comprehensive regulations around self-driving cars have been announced in the United Kingdom, with manufacturers being held liable for the vehicle's behavior, not the driver.
- AVs might need to learn to break the law when necessary to avoid obstacles, which poses complex legal challenges.

"People will try to blame the AV, so AVs will strictly adhere to the rules."

- For a broad introduction of automated driving, regulations will also need to facilitate it. This regulation requires multiple layers. The first layer is that of programmed traffic behavior, which largely consists of rules and regulations currently understood under traffic legislation. These need to be translated into functional behavior regulations for automated systems. In the book 'Do Normal Yourself,' Maxim Februari outlines the ongoing process in which law and regulations are increasingly digitized and converted into computer systems that apply these laws. While people may sometimes choose to interpret rules and bend them a little, algorithms do not do that in principle. This means that unenforceable or difficult-to-follow rules, which would normally be ignored, will be strictly adhered to by self-driving systems, potentially leading to irritation or even unsafe situations.
- A more fundamental problem is that the current procedure for creating these formal rules is bound to various forms of democratic participation: a citizen can lodge an objection when a municipality makes a traffic decision, thus exercising control over the legality, fairness, justification, and proportionality of a traffic measure. When this process is automated through technical standards, this control becomes less straightforward, especially if these rules can be automatically adjusted according to the circumstances.
- A second layer is that of informal behaviors. To what extent is it possible and necessary to codify them in regulations or other norms? Uniform driving behavior has many advantages, but if preferences for, for example, route choice become too restrictive, it may conflict with the traffic interest of freedom of movement; there is a big difference between a government kindly asking people to avoid a certain area and a government effectively closing that area for traffic through a traffic management system.
- The third layer concerns how liability and individual responsibility are organized. Currently, the vehicle owner is obliged to have insurance for damages resulting from their own behavior, and the driver is responsible for driving safely in traffic. The vehicle is tested for minimal safety requirements through the periodic technical inspection (APK in Dutch), and the road authority has a duty of care to prevent or promptly address unsafe traffic situations. What happens when a computer program drives the car? Is the programmer then responsible? Who insures this? How do you prevent 'big tech' from settling with individual citizens through settlements, instead of further improving vehicle safety? What if someone modifies their car? Currently, we already see that for older cars with driving assistance systems, owners find it too expensive to repair or replace sensors when they break or get damaged. Will these systems be included in the periodic technical inspection in the future? Will periodic checks on cybersecurity and safeguarding the privacy of occupants also be included in the type approval process?
- The issue of liability of the road authority is of particular importance in this context. With human drivers, the state of maintenance and any unclear design can be partly overcome because humans can improvise well. However, if vehicles are dependent on the road design and systems offered, prescribed, or enabled by the government, the government is much more liable. Not only for damages caused by accidents but also, for example, if a vehicle needs to stop for safety reasons due to unreadable road markings, causing passengers to experience delays and subsequent damages. Due to the financial and power positions of companies providing vehicles

and software, it is conceivable that the burden of liability for road authorities may increase significantly if not properly organized through new laws and regulations in a timely manner.

- The fourth layer pertains to the legislation and regulations related to data exchange. This includes both the level of permitting vehicles on Dutch roads and the services offered in and around the vehicle, such as traffic management. When working in the cloud to control this traffic, various combinations that can be traced back to personal data can quickly emerge. This calls for an active stance from governments that provide, develop, or authorize third parties to exploit these services in the digital public space.

Regulations regarding safety requirements:

- The Netherlands has the ambition to be at the forefront of autonomous transportation development, but complex regulations concerning safety requirements are putting pressure on the innovation climate. In 2016, the Declaration of Amsterdam on autonomous vehicles was established, aiming to make the Netherlands a leader in autonomous driving. However, the number of pilots and applications in the country is limited compared to the initial ambition due to the practical complexities of admission procedures. Technology has the potential to be much safer than human drivers ("a computer is not distracted and does not make phone calls"). Nevertheless, relying on a technical system in a complex and vulnerable traffic environment requires caution and a step-by-step, controlled approach. The challenge is not to become overly cautious to the extent that innovation stagnates.

"Fully autonomous driving is an extremely complex process, which almost by definition makes us 'overcautious.' This is almost unavoidable because systems cannot take as much risk as humans. When something obstructs the road, we drive around it, even if it means crossing a solid line. An autonomous vehicle does not do that. Ultimately, everything is solvable, technically and legally, but it is very expensive due to its complexity. The problem is not significant enough, which hinders real progress in all experiments. The biggest hype around autonomous transportation is gradually fading."

Inclusion:

- Regarding people with visual or other disabilities, a closed multimodal network that requires walking or cycling for the last mile may exclude visually impaired and elderly individuals. Ensuring inclusivity involves completing the journey using connected and autonomous vehicles (CAVs) or public transport to create an inclusive network.
- Affordability.

Public-private business case:

- To make progress across the board, a public-private business case is necessary. While this might slow down the rapid deployment of potentially suitable use cases for autonomous driving, it is essential for a responsible introduction to contribute adequately to societal goals.

Business case for automated driving - driver out of the vehicle:

"This applies to the use cases of transport, public transport, and taxi services. The transport use case is the most promising because public transport also involves social safety concerns, and the limited market for taxis in the Netherlands compared to, for example, the US."

- The use case for transportation is considered the most promising, as it may be possible to operate without a human driver on specific highway segments (point-to-point). The ability to operate without a driver is crucial for an attractive business case in the transport sector, primarily due to cost reduction. It offers fewer restrictions on driving times, greater flexibility in time slots (including nighttime driving), and the possibility of driving at lower speeds (the duration of the journey becomes less relevant). The absence of a driver is more critical for the business case than fuel consumption reduction through platooning. Platooning may not be necessary for this use case. However, the absence of a driver does not mean that no human intervention will be required. Loading and unloading at the endpoint of the journey may need to be done manually if not automated, requiring a loader/unloader. Additionally, for the first/last mile, a human driver might still be necessary. These factors significantly influence the viability of the business case and its expected large-scale realization.

Car-sharing: demand and viability

"In the future, people will no longer want to own a car but will purchase mobility as a service: sometimes using a car-sharing service, sometimes taking the train, sometimes using a bike-sharing service. The benefits of car-sharing are evident: it reduces the need for a large number of cars, thus decreasing the demand for resources and space."

"No matter how well-designed the system with apps may be, a car-sharing service can never fully replace the convenience of having one's own car parked at their doorstep. Owning a car is deeply ingrained in people's social fabric."

- Car-sharing is particularly interesting in relation to space constraints in cities, especially for parking.
- According to KiM (2021), only 2 percent of the Dutch population uses car-sharing services, accounting for 0.02% of the total number of car rides. Furthermore, car-sharing is also used as a replacement for public transport and bicycles. The commercial viability of operating car-sharing services, especially free-floating car-sharing services (without fixed parking spots), is not yet so attractive.
- Individuals value the car for its sense of personal freedom, and this perception has a long tradition. Over the years, cars have become relatively more affordable due to increased purchasing power.
- There is a difference between urban and rural areas. In cities, there is potential for further growth in car-sharing. Space is limited, and the growth of the car fleet cannot keep up, leading to increased regulation by municipalities, such as higher parking costs and access restrictions for cars. As a result, car ownership is decreasing in large cities. For young people, there is often a delay in purchasing a car, and that moment often coincides with moving from the city to the outskirts or rural areas. In rural areas, car ownership is increasing. People there rely on cars to access facilities and often drive more than the 10,000 km/year, which is currently a common threshold for the attractiveness of car-sharing.

5.6 Can we identify a tipping point (from human control to vehicle control)?

Regarding the tipping point from human-controlled to autonomous vehicles, various scenarios exist, either closer or further in the future. This is related to the application and acceptance of autonomous driving on a significant part of the road network or smaller sections that can be more easily tailored to the needs of autonomous vehicles.

- The first Connected Automated Transport corridors on highways could be possible within the next 10 years, with widespread application between 10-25 years from now. The Trans-European Transport Network (TEN-T) is seen as a promising candidate for this development.
- For other use cases on highways (main road network), concrete possibilities could emerge from 2030 onwards. This could start with automatic driving on highways, in line with the functions of ALKS (Automated Lane Keeping System), and possibly later complemented with cooperative driving, a cooperative form of ALKS/ACC (Adaptive Cruise Control). Highways are more suitable for autonomous driving than other types of roads due to the absence of slow-moving traffic, separated travel directions, and grade-separated intersections.
- Large-scale autonomous driving on the main structure of the secondary road network (expressways and main access roads) could become feasible from 2050 (an important aspect here is the grade-separated intersections and limited travel direction separation).
- For urban traffic, the tipping point will likely be much later, after 2060, if it ever comes, as the need and demand for widespread application of autonomous traffic in urban areas are considered much lower. It is very complex due to the numerous interactions with slow-moving traffic, making it also costly (see chapter 3).

Overall view: a clear indication of the tipping point is not yet possible due to the expected prolonged mix of vehicles with different levels of automation. This leads to the following observations regarding the road network and road infrastructure:

- In mixed traffic, substantial changes in design cannot initially take place. It remains based on what human drivers need to drive safely, smoothly, and comfortably. Only with a 100% fully automated vehicle fleet (or on routes where only those vehicles are allowed), can you consider different dimensioning of the cross-section (lane width, recovery zone, obstacle-free zone) and adjustments to the longitudinal profile and intersections and roundabouts. This applies to arterial roads and distributor roads but not to local access roads. On local access roads, the interaction with other road users (cyclists, pedestrians, light motorized traffic) is more influential in the design than the characteristics of the automated vehicle.

- A precise identification of the tipping point is not yet possible due to the expected prolonged coexistence of vehicles with different automation levels. Therefore, certain road design adaptations for future-proofing and facilitating the further development of autonomous vehicles are recommended.
- Good elements present in the current design (aimed at the human driver) are also important for smart vehicles. Refer to the three aforementioned fundamental principles (building on the Sustainable Safe vision). Redesigning roads differently for cost-saving purposes does not seem like a good choice.
- Gradual safety improvements of the traffic system should also take into account the properties of intelligent vehicles. *Conditional access to a segment of the road network would likely become interesting with a penetration rate of at least 70% (also for inclusivity). For freight transportation, this threshold might be lower.*
- As part of the above point, a stepwise development of the digital infrastructure is needed, providing digitally available information about the traffic environment and roads. This would allow for personalized adjustments to the vehicle's driving behavior, such as adopting an appropriate speed to navigate a curve.

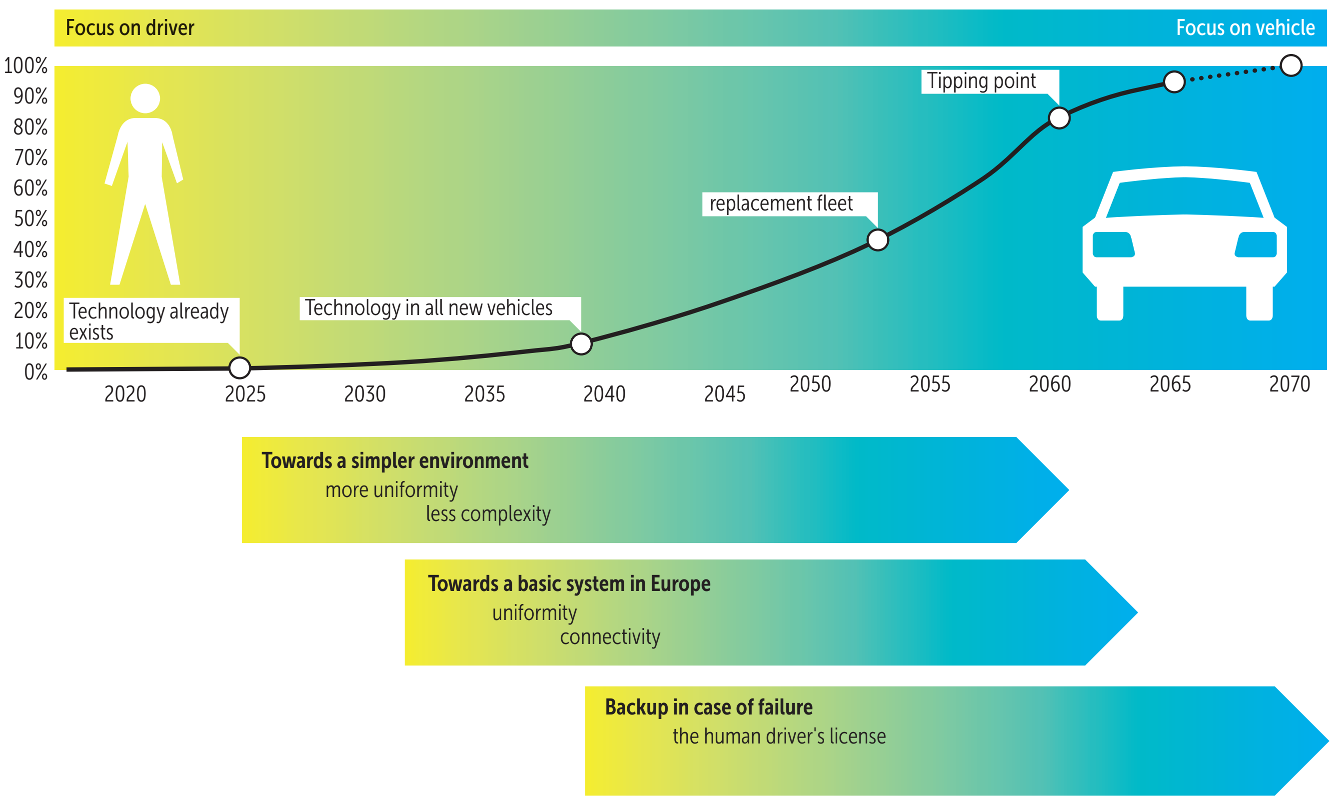


Figure 11. As soon as the technology is in all the new vehicles, we have to wait for the replacement of the fleet. This will take longer for private property because of the costs than for shared mobility or mobility services.

Shared mobility and autonomous driving can complement each other. Autonomous driving, due to cost factors, has a higher potential for car-sharing, which in turn can accelerate the replacement of the car fleet. Eventually (depending on technology, approval, and economic conditions), the tipping point will lie somewhere in the period between 2050 and 2060, where 70+% of vehicles will be autonomous, and human driving will become subordinate (at least for a part of the Operational Design Domain - ODD). Standardization and connectivity will facilitate this transition. The human driver's license will continue to serve as a backup if the vehicle encounters difficulties, unless this can be managed remotely. Europe currently allows the conditions for remote control to be determined by the individual member states. In a certain phase, a situation may arise where a driver's license is only necessary for door-to-door car journeys, not for point-to-point or hub-to-hub journeys. This could provide an additional boost to more shared mobility.

5.7 In conclusion, automated vehicles and road infrastructure: getting the basics right, reducing complexity, and increasing digitalization

Traditionally, in traffic management, planning, and regulations, our focus has been on humans as drivers of vehicles. The changing relationship between humans, vehicles, and roads means that we need to increasingly focus on the vehicle's role in the design and functioning of the traffic and transportation system. The interaction between intelligent vehicles and the traffic environment must be carefully examined. The benefits of automated driving can only be realized if the vehicles meet the requirements of the specific application area and conditions for which they are designed to operate safely and comfortably (the so-called Operational Design Domain - ODD). In addition to information about other road users, this also involves information about the physical infrastructure (road design and layout, signage) and information from the digital infrastructure (permissions, traffic, and route information). Together, these form the key attributes for the application area/ODD of automated vehicles.

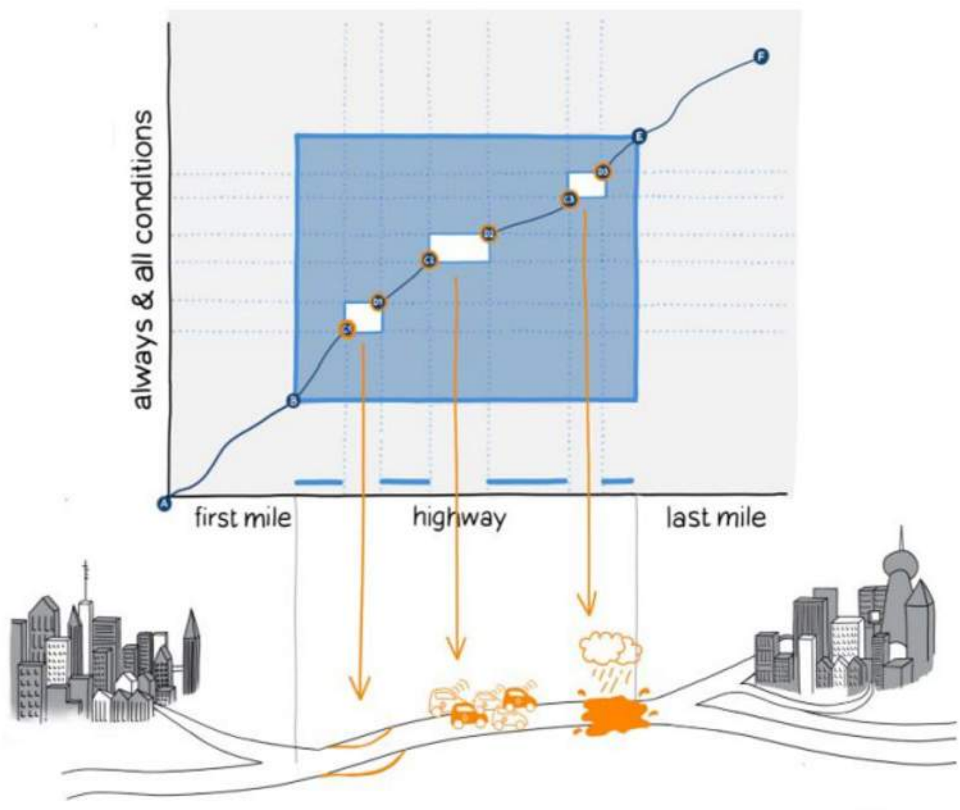


Figure 12. schematic representation of increasing the ODD for self-driving.

Road design and road infrastructure: starting with basic principles
A future-proof road infrastructure starts with consistently adhering to the basic principles:
- Reducing complexity.
- Increasing uniformity and consistency.

These principles are based on the well-known Sustainable Safe Traffic vision and are applicable to both human drivers and vehicles with various levels of automation. They also align with the duty of care of road authorities regarding adequate road infrastructure for all road users.
- To make the application of automated vehicles possible and attractive in the Netherlands, complex situations for both intelligent vehicles and humans should be minimized. Manufacturers focus on maximizing the Operational Design Domain (ODD) with as few interruptions as possible. Fewer interruptions mean fewer situations requiring fallback to manual control by the human driver. This reduces potentially risky transition situations and enhances the efficiency and attractiveness of automated vehicles.
- A consistent application of current road design and layout guidelines contributes significantly to uniformity and consistency. In the ongoing updates of the Road Design Manual and the Road Marking and Signage Guidelines, additional functional requirements related to marking and signage for the functioning of Advanced Driver Assistance Systems (ADAS) will be included. For example, good-quality markings (visible under various lighting and weather conditions) and proper positioning and visibility of traffic signs.
- If deviations from the guidelines are necessary, it is essential to ensure that automated vehicles can handle these deviations or customized solutions.
- These points may also lead to an upgrade of quality standards for maintenance and adjusted maintenance schedules.
- Infrastructure premise: no major changes to road design; the vehicle must know where it can use automatic functions and where they are allowed. In emergency situations, there must be enough space for controlled stopping and maneuvering ("minimum risk maneuver," for L4 and higher). Transitional areas should have sufficient space to facilitate the transition from automated to manual driving.
- The quality of the main road network is internationally considered good (e.g., regarding the quality of road markings and surfacing), and it is essential to maintain this, particularly from the perspective of automated vehicles. Special attention is required for phasing out or explicitly indicating complexities/special features (such as taper mergers and reversible lanes at interchanges) that cannot be solved through physical design adjustments in the short term. A good dialogue with manufacturers is crucial for this.

Digital infrastructure
Digitalization plays a significant role in the transition to autonomous driving. Systems like Intelligent Speed Adaptation (ISA) partly rely on data, and looking to the future, ISA could pave the way for digitally imposing variable speeds depending on conditions like traffic density and road conditions. Road authorities are already preparing to have relevant data available through the Real-Time Traffic Information (RTTI) EU regulation and the Data Top 15. This includes information on road works and preferred routes, which, through policy processing via the RTTI regulation, will also reach service providers in navigation systems. An increase in digital information and further-developed digital service levels for roads will lead to more situations where automated vehicles can drive safely and comfortably (ODD expansion) and receive timely in-car signals about situations outside the ODD.
Moreover, this will enable innovative forms of traffic management, such as preferred/allowed route choices and the aforementioned customized speed control for automated vehicles.

Fewer complexities, efficient maintenance, and increasing digitalization
The transition to autonomous driving benefits from reducing complexities and tidying up the traffic environment. This means gradually phasing out physical elements (special features in road design and DVM-assets) during the development of infrastructure. This depends on the road type and considering uniformity and consistency. The condition of the road is also essential for the functioning of automated vehicles, similar to human drivers. Extra attention to the visibility of, for example, markings and signs under varying weather and lighting conditions necessitates a reevaluation/revision of quality standards for maintenance. However, intelligent vehicles also provide a continuous flow of information about the condition of assets, enabling proactive and demand-driven maintenance. Concurrently, it is essential to further expand the digital infrastructure (partly) for the benefit of automated vehicles, also as part of the physical simplification. The primary focus should be on roads that are already highly suitable for automated driving (low complexities and ODD interruptions) in terms of physical infrastructure. The digital infrastructure will increasingly function as a digital twin of the physical infrastructure, with HD maps (digital navigation maps) as the interface towards the vehicle and connectivity as the keyword. All information reaches the vehicle through a mix of own perception, communication with the environment, data, and central control.

5.8 Finally: predictions regarding the timeline for widespread implementation of fully autonomous driving (sae level 5)

Various developments in the field of automated traffic and transportation have already been set in motion in recent years, although not all of them have been equally successful. These developments are characterized by a search for balance between what is already technically feasible and where the most significant challenges, needs, and business models lie. We do observe that the developments in connectivity and the gradual automation of driving tasks (shifting tasks from the driver to the vehicle) continue steadily and seem irreversible, as seen in the EU General Safety Regulation (GSR) and Implementing Act.

The pace of these developments is more difficult to predict, but in this concluding paragraph, we would like to provide some perspectives and observations on the timeline towards widespread implementation of fully autonomous driving.

"There is a future in fully autonomous driving, but the large-scale rollout is a complex process and seems further away at the moment than it did some time ago, especially when it comes to busier or urban environments. Lately, expectations have been slightly adjusted downward. Moreover, the required investments are very significant."

This statement accurately reflects recent literature and input from various interviewed experts. When translating this into possible timelines for widespread, fully autonomous driving (level 5), Figure 13 provides a good illustration of projections from two expert sources, ERTRAC (European perspective) and KIM (Netherlands in an international perspective). The figure also shows how these predictions have been adjusted and are converging over the past few years.

Key questions:
- Why do we want fully self-driving level 5?
- How can public and private parties collaborate and reinforce each other for the responsible introduction of automated transportation?

When addressing these questions, attention should be given to the following aspects: technology/vehicle, human/needs and acceptance, and ODD/traffic environment.

Technology/vehicle:
- Despite all futuristic forms of automated vehicles, it is expected that vehicles (both passenger and commercial) will remain fundamentally the same (largely retaining their conventional form). This means no major changes in vehicle dynamics aspects, driving characteristics, turning radii, tire-road contact, etc. Therefore, no significant changes in the principles of road design are expected based on the size and driving characteristics of automated vehicles.
- Vehicles are expected to become heavier initially due to electrification (but that is essentially independent of automation). However, advancements in sustainable propulsion technology and the use of new materials are expected to limit the weight increase.
- Possible civil engineering implications of track formation by automated vehicles that follow the same path within a lane for prolonged periods need further investigation.

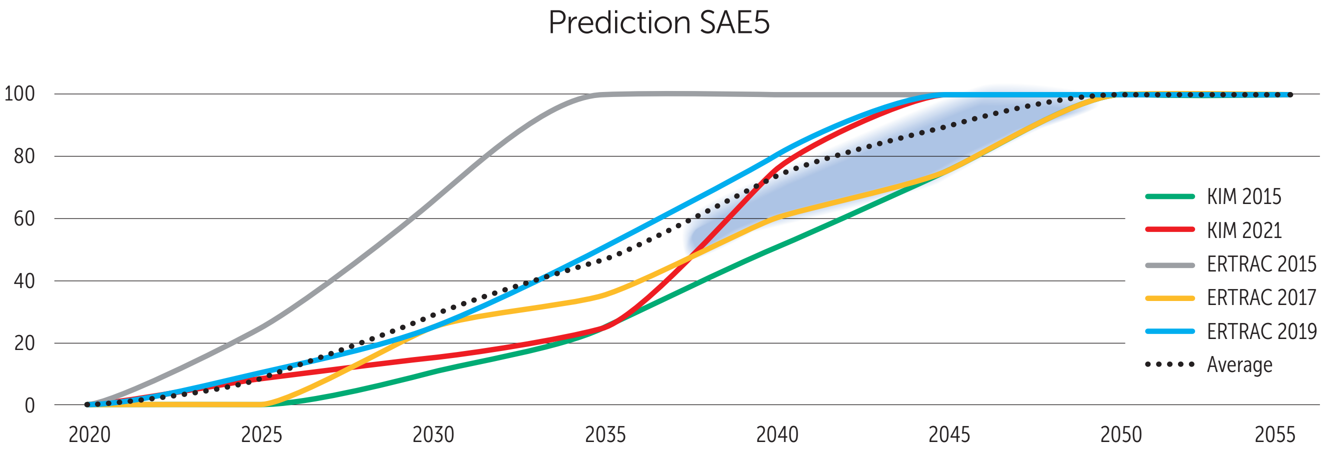


Figure 13. From the literature we see that predictions of level 5 from the roadmaps of ERTRAC and KIM For now, the roadmaps make it difficult that in the period 2035-2045 the technology must be broad.

- Significant safety improvements can already be achieved with level 4 automation (point-to-point). Level 5 mainly offers increased comfort, where, compared to level 4, only the first and last mile are managed in a highly complex environment (mix of road users), making it expensive to realize.
- Level 4 automation, not only on highways but also on main roads, is expected to take some time. If there is a need for the driver to take over the driving task, sufficient time must be available (more than the often mentioned Time of Change of 7 seconds) or the vehicle must be capable of parking itself responsibly.

"That is because the intelligence of vehicles is overestimated. An exponential increase in technology leads to a linear increase in the intelligence of the vehicle."

- Automated vehicles learn differently from situations encountered in traffic than humans (relationship with driver's license for the automated vehicle). Therefore, it is important that vehicles from different brands share their experiences (challenges in organizing that effectively).

Human/needs and acceptance:

- Support humans where support is most needed, such as on long, monotonous routes, during distractions, for long-duration repetitive tasks, consistent adherence to traffic rules, in cases of human visibility obstruction, limitations in human perception, information processing, cognition, and to compensate for human reaction time. Situations from the mentioned list that are acceptable and have explained added value where needed (via adequate product information, driver training, etc.).
- Support is less suitable in a traffic environment where (mostly social) interaction between various types of road users is required (in urban areas and especially on access roads). Situations where traffic rules need to be flexibly interpreted for safe, smooth, and comfortable traffic flow.
- The above points are particularly relevant from the perspective of traffic safety. Human drivers can prevent errors and handle risky situations that automated vehicles may have more difficulty with.

ODD/traffic environment:

- SAE 5 (full automation) across the entire network is unlikely and currently beyond the scope. There is no problem that needs to be solved to justify investments outweighing the returns.
- Full automation (Level 4) on designated and deemed suitable road types/routes and specific times. Link with vehicle admission and conditional access.
- The most promising application is point-to-point logistics (Level 4) where the vehicles are driven by a driver to the main corridor. This may happen earlier in transportation before passenger transport.
- Robotaxis applications are already present in the US. However, the operators have not yet finalized their business case (despite a much larger taxi market there than in

the Netherlands) and have no intentions to export the application outside the US. Robotaxis in Europe may be interesting in the evening/night in a specifically configured area. Shared, electric Level 4 vehicles or as an automated shared vehicle with a destination of a city hub for intermodal transfer.
- Widespread implementation of automated driving in the city with other vehicles acting as taxis is seen as too complicated and expensive. However, Level 4 could provide value in urban environments during events.
- Level 4 automation is likely more interesting for rural applications in the Netherlands than in the city. But is there a viable business case? For now, there seems to be clear consumer demand/business case mainly on the main road network in urban areas, not on every street, but mainly at entry points (otherwise the distances become too large). A structure that accommodates the "5-minute AV" is needed, accessible within 5 minutes in the city on roads where they come, simply designed conflict-free, with low speed, *and possibly connecting to city hubs (as mentioned above).*

Point to point:
One of the first use cases that will develop in both transportation and public transport is the so-called point-to-point journeys where the vehicle could eventually operate without a driver. In public transport, a driver can take over during a specific period at points where the bus or tram encounters a still too complicated Operational Design Domain (ODD) on the route. The key here is to extend the self-driving ODD for as long as possible.

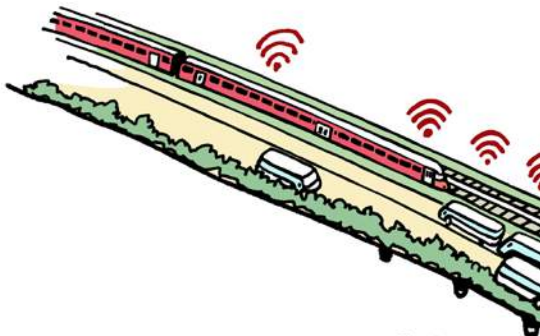
For transportation, this point-to-point approach will first be implemented on the TEN-T network, as seen in developments in the southern United States. The important aspect here is that point-to-point transport from a distribution center, port, or industrial area as the starting point should also have it as the endpoint.

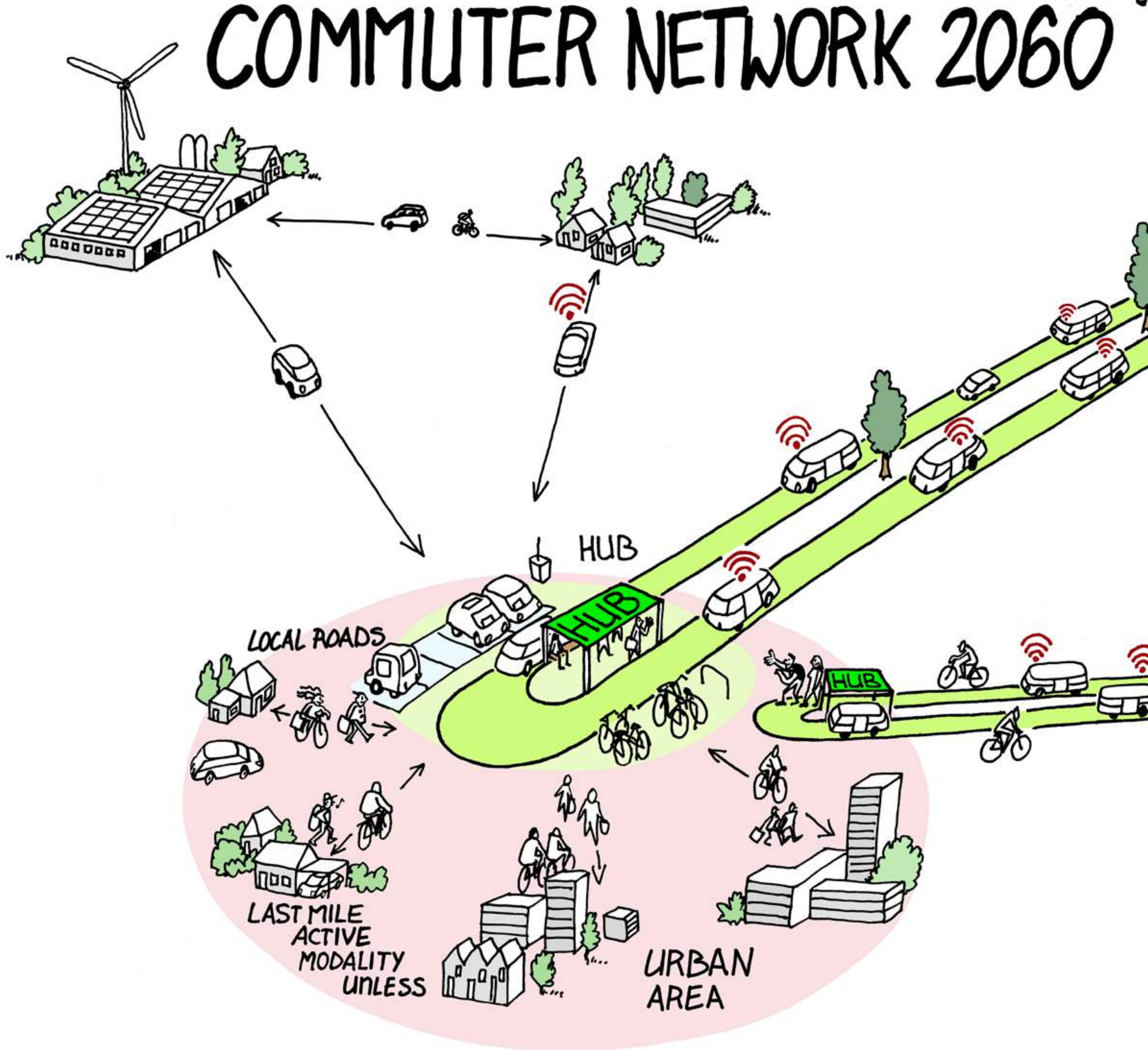
A possible phase could involve dedicated lanes or roads where only self-driving vehicles (of a specific category) are allowed.

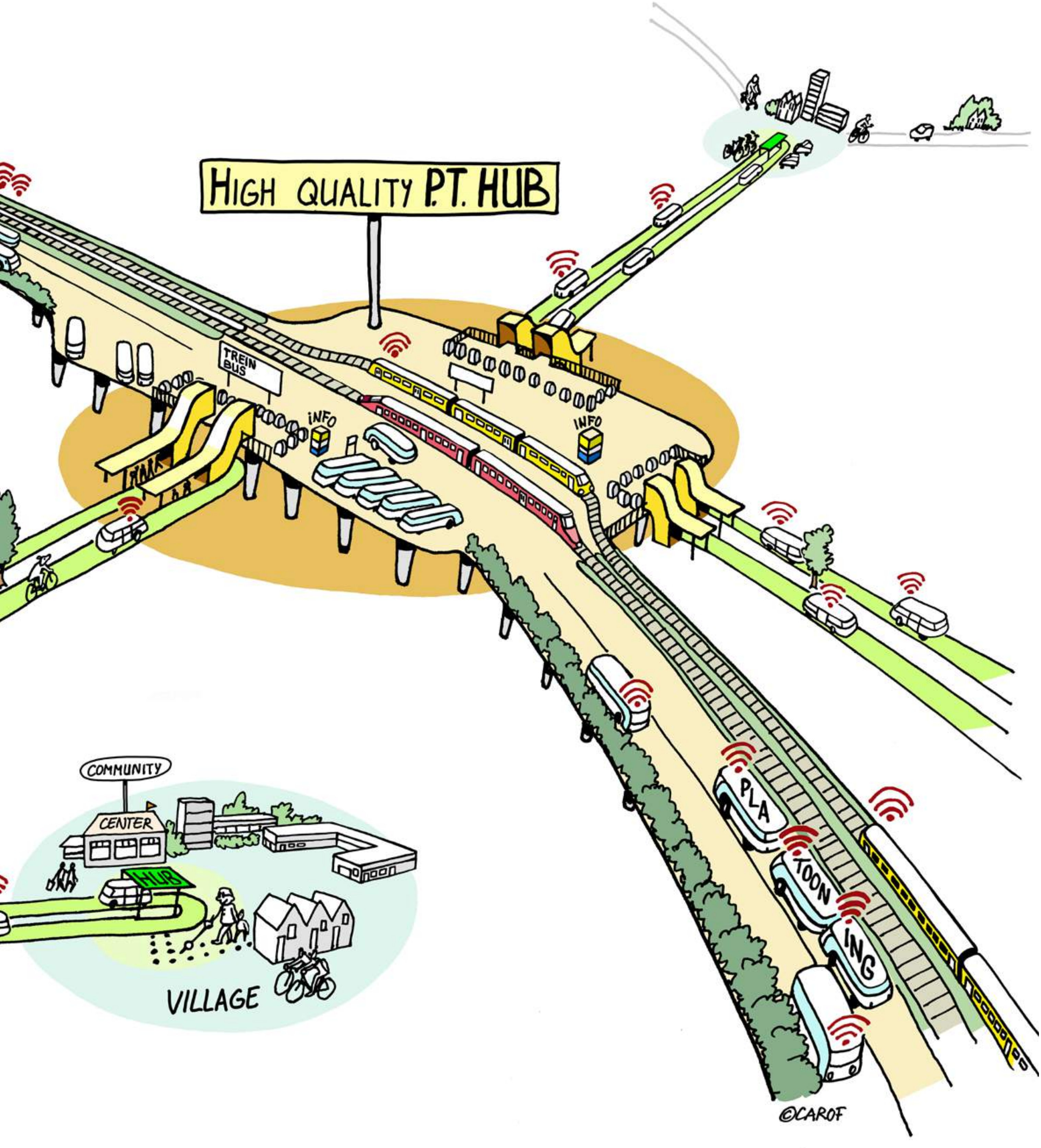
Part 3

Appendix 1: Schematic overview of mobility system 2060

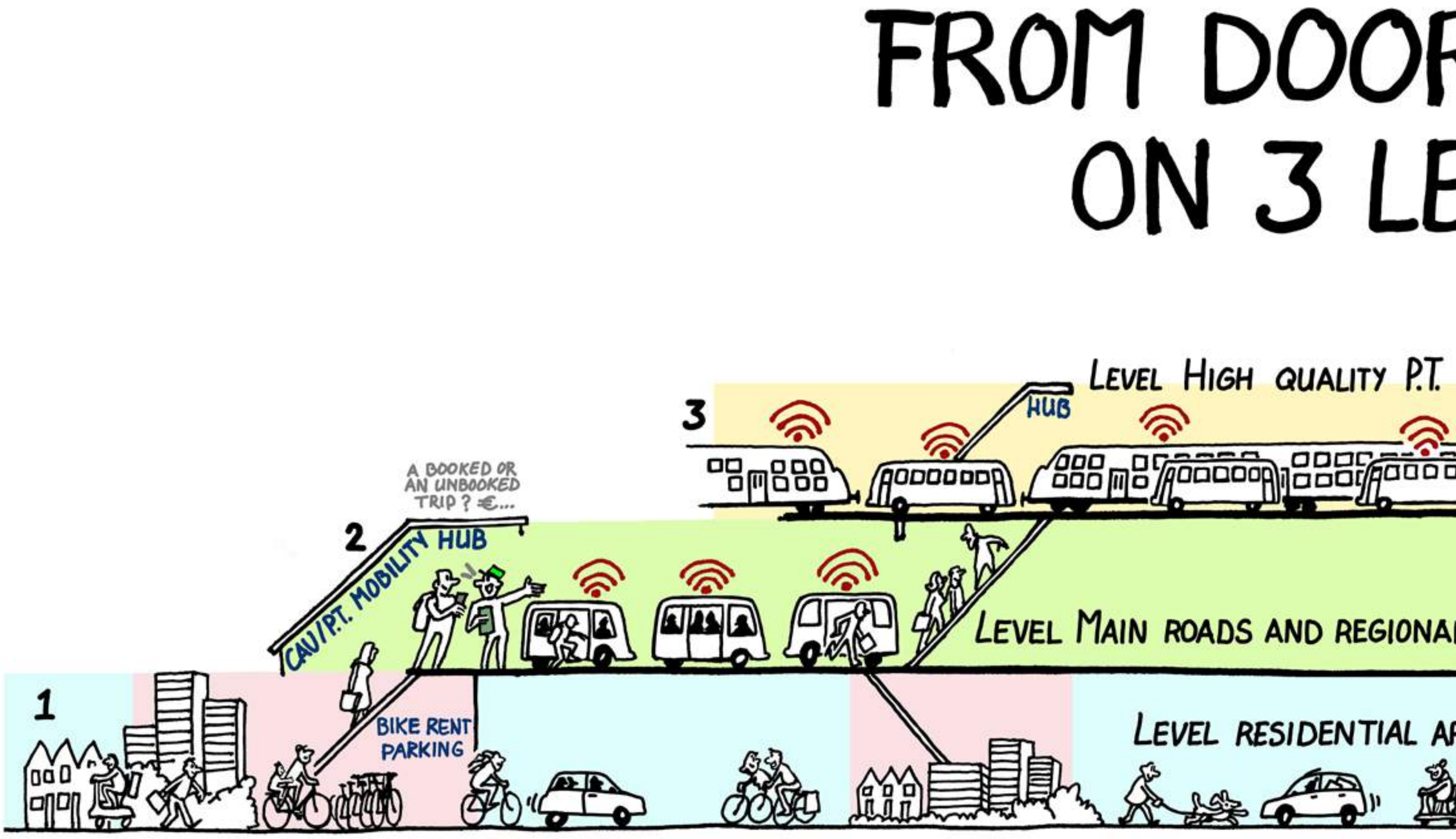
System overview
Schematic representation of the mobility system in the three layers: neighborhood, hub to hub, and HOV corridor, including the connection between the city and the region. Public transport and individual transport are converging, leading to a decrease in car ownership in urban areas. This creates more space. Active modes of transport have become the primary mode for short trips in urban areas, and shared mobility becomes more prevalent. Additionally, there will still be some private ownership, especially in the regions. The system needs to remain affordable and inclusive for all users.

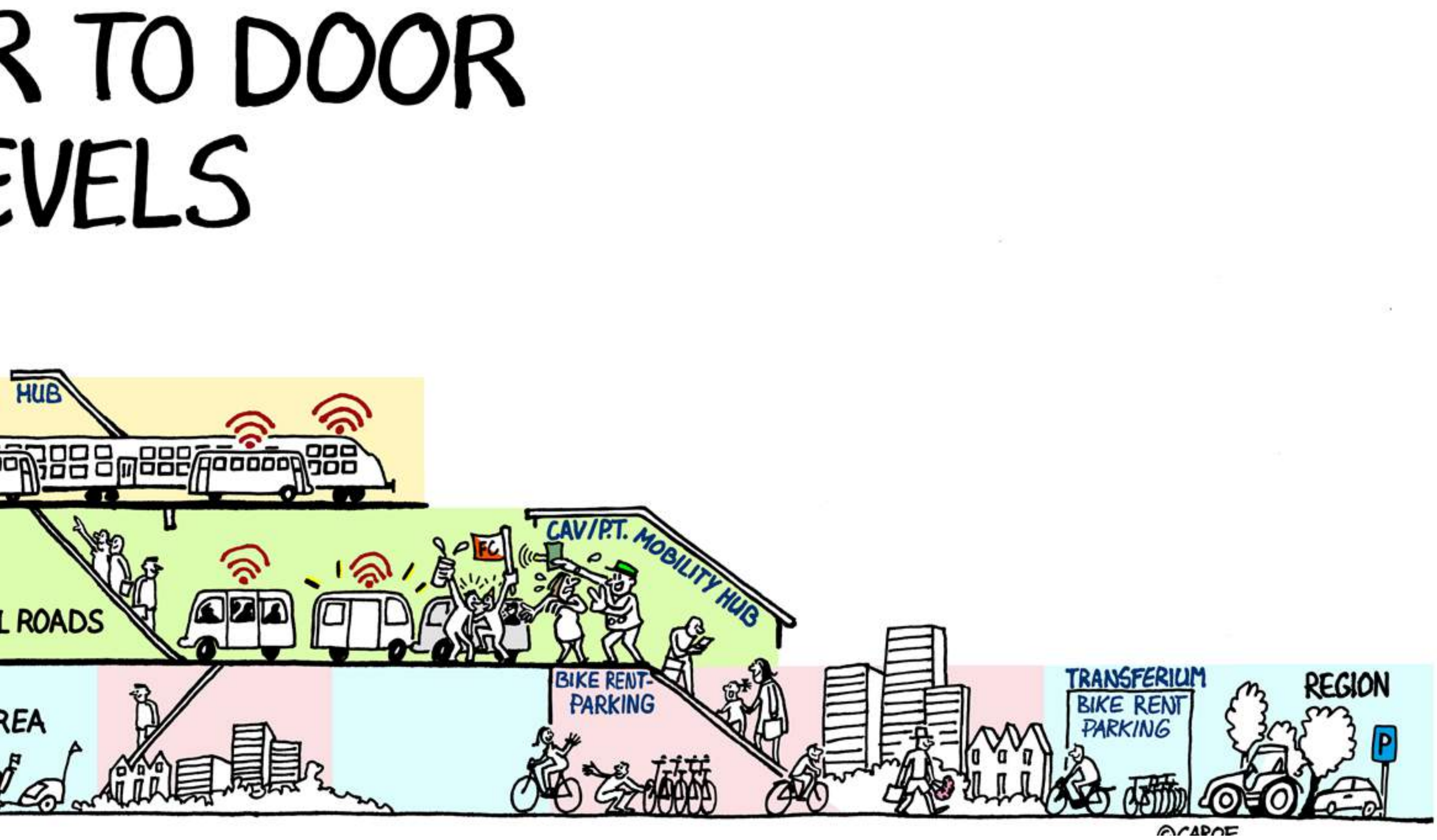





HIGH QUALITY P.T. HUB
TREIN
BUS
INFO
INFO
COMMUNITY
CENTER
HUB
VILLAGE
PLA
TOON
ING
©CAROF

Cross-section
Schematic cross-sectional diagram of the mobility system in the three layers: neighborhood, hub to hub, and on high frequently public transport corridors.




R TO DOOR
EVELS
HUB
L ROADS
CAV/P.T. MOBILITY HUB
FC
REA
BIKE RENT-
PARKING
TRANSFERIUM
BIKE RENT
PARKING
REGION
P

Appendix 2: List of consulted literature

Title	Author	Year	Link	Country
Smart Roads Classification	Garcia A. et al.(Universitat Politecnica de Valencia)	2023		World Road Association (PIARC)
Preparing Infrastructure for Automated Vehicles	International Transport Forum (ITF)	2023	Preparing Infrastructure for Automated Vehicles | ITF (itf-oecd.org)	OECD
Beleidsvisie Toepassing Geautomatiseerd Wegvervoer Versie 0.9 (final draft)	Ackerman A.A.	2023		
Computers that power self-driving cars could be a huge driver of global carbon emissions	Adam Zewe	2023	Link	
SAE's Driving Automation Standard Is Not a Road Map	Colin Barnden	2022	Link	-
Underground Autonomous Cargo Delivery	EVAN ACKERMAN	2022	Link	
Visualisaties helpen ons de toekomst te zien	Thomas Pelzer	2022	Link	
Self-driving cars rules added to the Highway Code - What you can and can't do	Hannah De Boltz	2022	Link	
Uitstel lelylijn: over 2,5 jaar meer duidelijkheid. Alternatieven: hyperloop of elektrisch vliegen op Amsterdam?	Klaas Jan ter Veen	2022	Link Link	
Do adaptive cruise control and lane keeping systems make the longitudinal vehicle control safer?	SWOV	2022	Link	
Column Caspar de Jonge: Auto's uit de stad? Het kan en het gebeurt al!	NM magazine	2022	Link	
Connected, Cooperative and Automated Mobility Roadmap	ERTRAC Working Group: 'Connectivity and Automated Driving'	2022		
Kunnen stepjes en zelfrijdende (deel)auto's meer reizigers in het ov krijgen?	Nick Augusteijn	2022	Link	
Webinar toekomstig stedennetwerk	I&W	2022	Link	
C-ITS: Europe's Path to Connected, Cooperative & Automated Mobility	C2C consortium CCAM	2022	Link	
Roadmap Zelfrijdende Shuttle 2030 in Nederland	Henk Meurs Rebecca Rommerts	2022		
MRA Multimodaal toekomstbeeld 2040		2021	Link	
Webinar Luuk Verheul	Luuk Verheul	2021	Link	

Title	Author	Year	Link	Country
AutoX Opens Its Fully Driverless RoboTaxi Service to the Public in China	Auto X Team	2021	Link	
Afweegkader aanleg en onderhoud verkeerssystemen Hoe Smart Mobility verkeerssystemen gaat veranderen	RWS	2021		
https://www.connekt.nl/wp-content/uploads/2021/04/Snelheid-maken-met-het-focuspunt-Smart-Mobility-juni-2020.pdf	RWS	2021	Link	
Guidelines and recommendations for future policy of cooperative and automated passenger cars	Deliverable D6.5 – WP6 – PU	2021		
Travellers' preferences towards existing and emerging means of frst/last mile transport: a case study for the Almere centrum railway station in the Netherlands	European Transport Research Review	2021	Link	
Whitepaper automatisch rijden RWS		2021		
CCAM Strategic Research and Innovation Agenda (SRIA)	EC	2021	Link	
Autonomous Vehicles Readiness Index (AVRI)	KPMG	2020	Link	
Monitoren van de transitie naar autonoom vervoer	KIM	2020	Link	
Autonoom wegtransport in 2030	ACE	2020	Link	
5G Strategic Deployment Agenda for Connected and Automated Mobility in Europe	DG Connect	2020	Link	
Automatisierter und vernetzter Verkehr: Entwicklungen des urbanen Europa	Aveneu 21 Austria	2020	Link	
Ensuring American Leadership in Automated Vehicle Technologies	US DoT	2020	Link	
Expectations and Concerns of Connected and Automated Driving	JRC	2020	Link	
Future Agenda open foresight; the future of autonomous vehicles; Global Insights gained from Multiple Expert Discussions	High Level Structural Dialogue on Connected and Automated Driving, UK	2020	Link	
Guidelines How to become an automation-ready road authority	CoEXist	2020	Link	

Title	Author	Year	Link	Country
HTSM Automotive Roadmap 2020-2030	HOLLAND HIGH TECHIndustry	2020	Link	
Intelligent Transportation Systems (ITS) Joint Program Office: Strategic Plan 2020–2025	U.S. DOT	2020	Link	
Road map and action plan to facilitate automated driving on TEN road network – version 2020	EIP	2020		
Future of Rail 2050	Marcus Morrel Chris Luebkeman Lynne Goulding	2019	Link	
Autonomous vehicles' impact on port Infrastructure requirements	Dipl.-Ing. Ralf Fiedler Dipl.-Ing. Claudia Bosse Daria Gehlken, B.Sc. Katrin Brümmerstedt, M.Sc. Dipl.-Wirtsch.-Ing. Univ. Hans-Christoph Burmeister	2019	Link	
A CAV Roadmap for Scotland	United Kingdom	2019	Link	
Automated and Connected Vehicles Policy Framework for Canada	Policy and Planning Support Committee (PPSC) Canada	2019	Link	
CAD consolidated roadmap	Arcade	2019	Link	
Canada's Safety Framework for Automated and Connected VehiclesTransport	Public authority Strategy Canada	2019	Link	
Cross-ministerial Strategic Innovation Promotion Program (SIP) Automated Driving for Universal Services R&D Plan Director General for Science,	Cabinet Office Public authority Strategy Japan	2019	Link	
Defining the future of 1) urban transport, 2) freight transport, and 3) passenger car transport	Levitate	2019	Link	
EATA Roadmap	EATA	2019	Link	
Manifesto European Automotive and Telecoms Alliance Road map	EATA	2019	Link	
Research and innovation in connected and automated transport in Europe	JRC	2019	Link	
Road vehicle automation in sustainable urban mobility planning Practitioner Briefing	European Platform on Sustainable Urban Mobility Plans	2019	Link	
Roadmap for the deployment of automated driving in the European Union	ACEA	2019	Link	
The future of road Transport – Implications of Automated, Connected, Low-carbon and Shared Mobility	JRC	2019	Link	

Title	Author	Year	Link	Country
UK Connected and Automated Mobility Roadmap to 2030	Zenzic	2019	Link	
Who's in control? Road safety and automation in road traffic	Dutch Safety Board	2019	Link	
R4E project		2018	Link video Roadmap SM	
3rd High Level Meeting on connected and Automated DrivingHigh Level Structural Dialogue on Connected and Automated DrivingEU	Government offices of Sweden	2018	Link	
4th High Level Meeting on Automated and Connected MobilityHigh Level Structural Dialogue on Connected and Automated DrivingEU	Federal Ministry of Austria	2018	Link	
Austrian Action Programme on Automated Mobility (2019-2022)	Federal Ministry of Transport, Innovation and Technology Austria	2018		
Development of Autonomous Vehicles Strategic Orientations for Public Action	French Ministry for the Ecological and Solidary Transition	2018		
State of play of Connected and Automated Driving and future challenges and opportunities for Europe's Cities and Regions	Committee of the Regions	2018	Link	
Paden naar een zelfrijdende toekomst	KIM	2017	Link	
2nd High Level Structural DialogueHigh Level Structural Dialogue on Connected and Automated DrivingEU	The federal Government of Germany	2017	Link	
A roadmap for developing automation and robotics in the transport sector 2017–2019	Finnish Transport Agency	2017	Link	
Draft Roadmap and Action Plan to facilitate automated driving on TEN road network	EIP	2017	Link	
EU Roadmap for Truck Platooning	European Automobile Manufacturers Association	2017	Link	
Final Report Ethics Commission Automated and Connected Driving	Federal Ministry of Transport and Digital Infrastructure Germany	2017	Link	
Autonomous Vehicles Code of practice for testing in Belgium	Belgium transport authority	2016		
CEDR Position on Road Vehicle Automation	CDER	2016	Link	

Title	Author	Year	Link	Country
Declaration of Amsterdam "Cooperation in the field of connected and automated driving	EC	2016	Link	
Federal Automated Vehicles Policy	US DoT	2016	Link	
On the road to automated driving: overview of the advances made so far and furtherprogress required to make automated driving a reality	JAMA Industry Roadmap Japan	2016	Link	
Spanish approach on Autonomous driving	Dirección General de Trafico, Spain	2016	Link	
Testing autonomous vehicles in New Zealand	Ministry of Transport, NZ	2016	Link	
Automated vehicles – The Coming of the Next Disruptive Technology	The Conference Board of Canada Research Institute	2015	Link	
Connected/Automated Vehicle Research Roadmap for AASHTO	Public authority Report Australia	2015	Link	
RoadmapUnited States	US DoT	2015	Link	
European Roadmap Smart Systems for Driving	European Technology Platform on Smart Systems Integration	2015	Link	
Roadmap for Autonomous (Self-Driving) Vehicles in Ontario	Public Authority Roadmap Canada	2015	Link	
The Pathway to Driverless Cars – a detailed review of regulations for automated vehicle technologies	Department for Transport United Kingdom	2015	Link	
Truck Platooning Driving the Future of Transportation	TNO	2015	Link	
Automation in Road Transport	EC	2013	Link	
Monitor Informatiediensten geeft waardevolle kijk op de praktijk	n/a	n/a	Link	
Connected, Cooperative and Automated Mobility	CDER			
Cooperative ITS towards Cooperative	C-ITS platform EC		Link	

Appendix 3: List of abbreviations and concepts

ACC
Adaptive Cruise Control
A system that attempts to drive the vehicle at a speed and/or following distance set by the driver using automation and sensors.

ADAS
Advanced Driver Assistance Systems
The collection of driving assistance systems that support the driver in performing (part of) the dynamic driving task or provide safety-related information.

ADS
Automated Driving System
The hardware and software together capable of performing the dynamic driving task (DDT) for an extended period, regardless of whether the system is limited to a specific operational design domain (ODD). ADS specifically refers to Level 3 to 5 Driving Automation Systems (DAS).

AI
Artificial Intelligence

ALKS
Automated Lane Keeping System
The hardware and software activated by the driver, which keeps the vehicle within its lane by controlling lateral and longitudinal movements for an extended period without further input from the driver.

APK
General Periodic Inspection (MOT)

AV
Automated Vehicle
A vehicle with an Automated Driving System (ADS) that uses hardware and software to perform the dynamic driving task within a defined operational design domain (ODD) (see also CCAM, CAV, and ZRA).

CAV
Connected Automated Vehicle (see also AV, CCAM, and ZRA)

CBR
Central Office for Driving Certificates

CCAM
Connected, Cooperative, Automated Mobility (see also AV, CAV, and ZRA)

Conflicts
Situations where the convergence or crossing of traffic flows may lead to mutual hindrance or traffic accidents.

Digital twin
A virtual representation of the real world.

DRIP
Dynamic Route Information Panel (also known as VMS)

DVM
Dynamic Traffic Management
Influencing the demand for and supply of traffic facilities and their interaction based on the state of the traffic system.

ERTRAC
European Road Transport Research Advisory Council

ETW
Local Access Road (also known as GOW and SW)
Intended to provide access to properties.

GNSS
Global Navigation Satellite System

GOW
Arterial Road (also known as SW and ETW)
A road on which traffic can flow on road sections and exchange at intersections.

GSR
General Safety Regulation
Regulation (EU) 2019/2144 of the European Parliament and of the Council of 27 November 2019 on type-approval requirements for motor vehicles and trailers thereof, and systems, components, and separate technical units intended for such vehicles, regarding their general safety and the protection of vehicle occupants and vulnerable road users.

HD maps
Digital navigation maps

HOV
High-Occupancy Vehicle
A term commonly used in the Netherlands for urban and regional transport that meets high requirements in terms of flow, comfort provision, and travel information at both stops and in the vehicle.

HUB
A mobility hub is a node in a multimodal mobility network where various modes of transport and their infrastructures, sizes, and scales converge. A hub serves as a starting, ending, or transfer point in the journey. Distinctions can be made between flows of people and flows of goods (logistics and urban distribution), which may overlap.

ICT
Information and Communication Technology

Implementing act ADS
Implementing Regulation (EU) 2022/1426 of the Commission of 5 August 2022 establishing implementing provisions for Regulation (EU) 2019/2144 of the European Parliament and of the Council regarding uniform procedures and technical specifications for the type-approval of Automated Driving Systems (ADS) for fully automated vehicles.

ISA
Intelligent Speed Assistant
A system to help the driver maintain the appropriate speed for the road environment by providing specific and appropriate feedback.

ISAD
ISAD are infrastructure support levels that can be assigned to parts of the network to guide automated vehicles and their drivers in the "readiness" of the road network for future road automation.

iTLC
Intelligent Traffic Light Controller

KIM
Netherlands Institute for Policy analyses

MIRT
Multi-Year Program for Infrastructure, Spatial Planning, and Transport

MTM
Motorway Traffic Management system

ODD
Operational Design Domain
The conditions for which automated driving systems or parts thereof are designed, including the environment, geographical limitations, time of day, and/or specific traffic or road conditions.

OV
Public Transport
Open to everyone, scheduled passenger transport using a car, bus, train, metro, tram, or a vehicle propelled by a guiding system. Public transport can also be carried out by ship.

PBL
Netherlands Environmental Assessment Agency

RDW
Netherlands Vehicle Authority

RISM II
Road Infrastructure Safety Management II

RTTI
Real Time Traffic Information

RWS
Directorate-General for Public Works and Water Management (Rijkswaterstaat)

SAE level
Levels of Driving Automation

Smart Mobility
The enhancement of mobility through the use of innovative techniques and data, in the context of the vehicle, human, and infrastructure interaction, to promote an accessible, vibrant, and healthy living environment, with an affordable, available, and green transportation system in the city and region, through connectivity in a cooperative public-private chain.

Spot on the horizon
the idea of a specific, visible goal or target in the future. It represents something to strive for or move towards, much like a physical point or spot on the distant horizon that you can see and aim to reach.

SUMP
Sustainable Urban Mobility Plans

SW
Expressways (also known as ETW and GOW)
A road intended for the smooth passage of traffic.

SYROPS
Synchronous Roundabouts with Rotating Priority Sectors

TDI
Entrance Dose Control System (Traffic Metering)

TEN-T
Trans-European Transport Network

Tidal flow
Traffic that alternately predominates in one direction and then the other, depending on time or other periodically occurring conditions.

V2X
Vehicle to Everything
The sharing of data between vehicles and other vehicles, infrastructure, other road users, or any other communication system in one or two directions.

VM-IVRA
Traffic Management Information for Route Advice
Tailored smart route advice.

VMS
Variable Message Sign (also known as DRIP)

ZRA
Automated Vehicle (applied in the illustrations; see also AV, CCAM, and CAV)

Colofon

Future proof road infrastructure – An exploration of the impact of automated traffic and transportation

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Interprovinciaal Overleg
van en voor provincies

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