Ministry of Infrastructure and the Environment

KiM | Netherlands Institute for Transport Policy Analysis

Paths to a self-driving future

Five transition steps identified

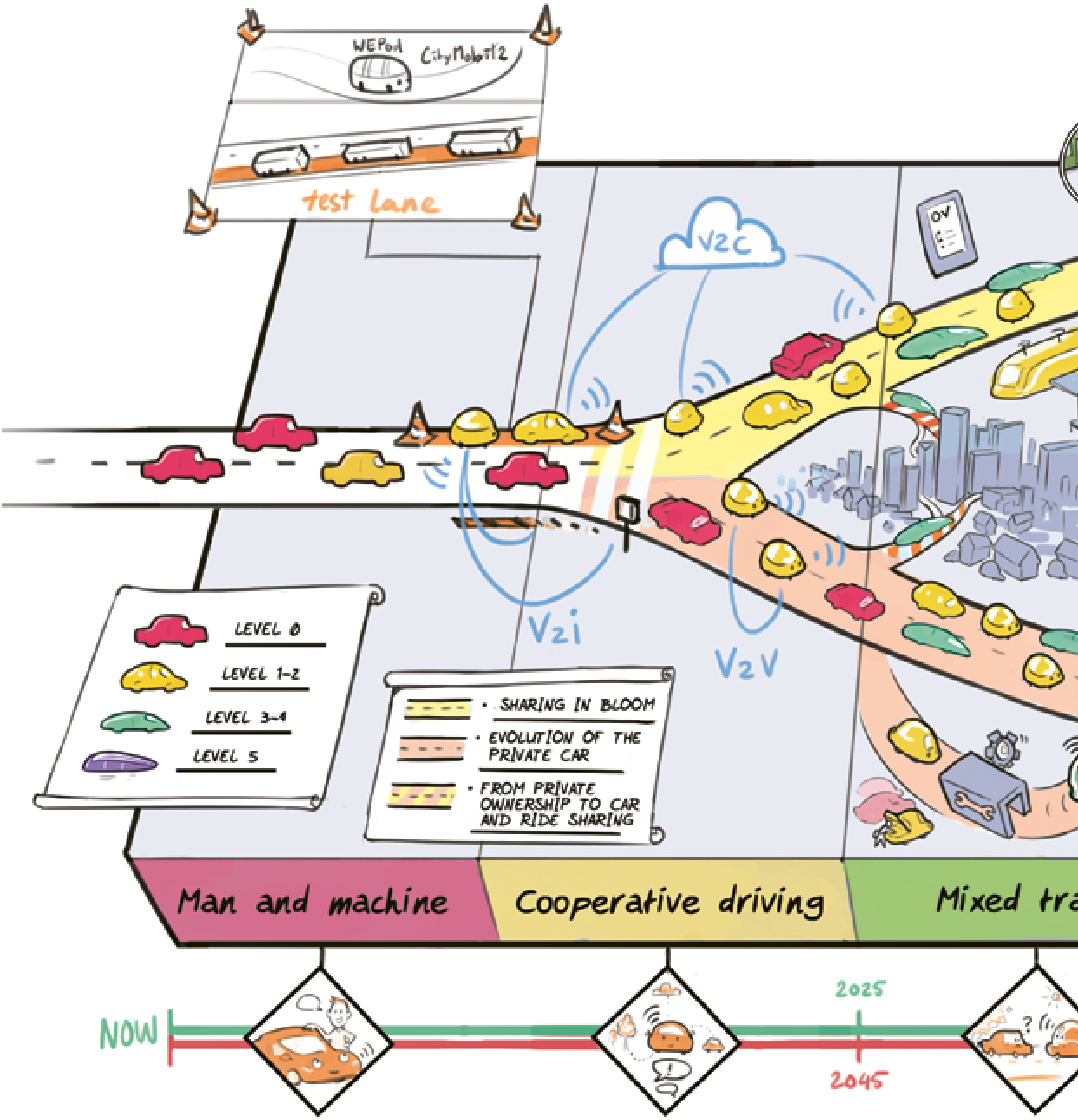
Man and machine

Cooperative driving

Mixed traffic

Urban dilemma

Self-driving city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LEVEL 0
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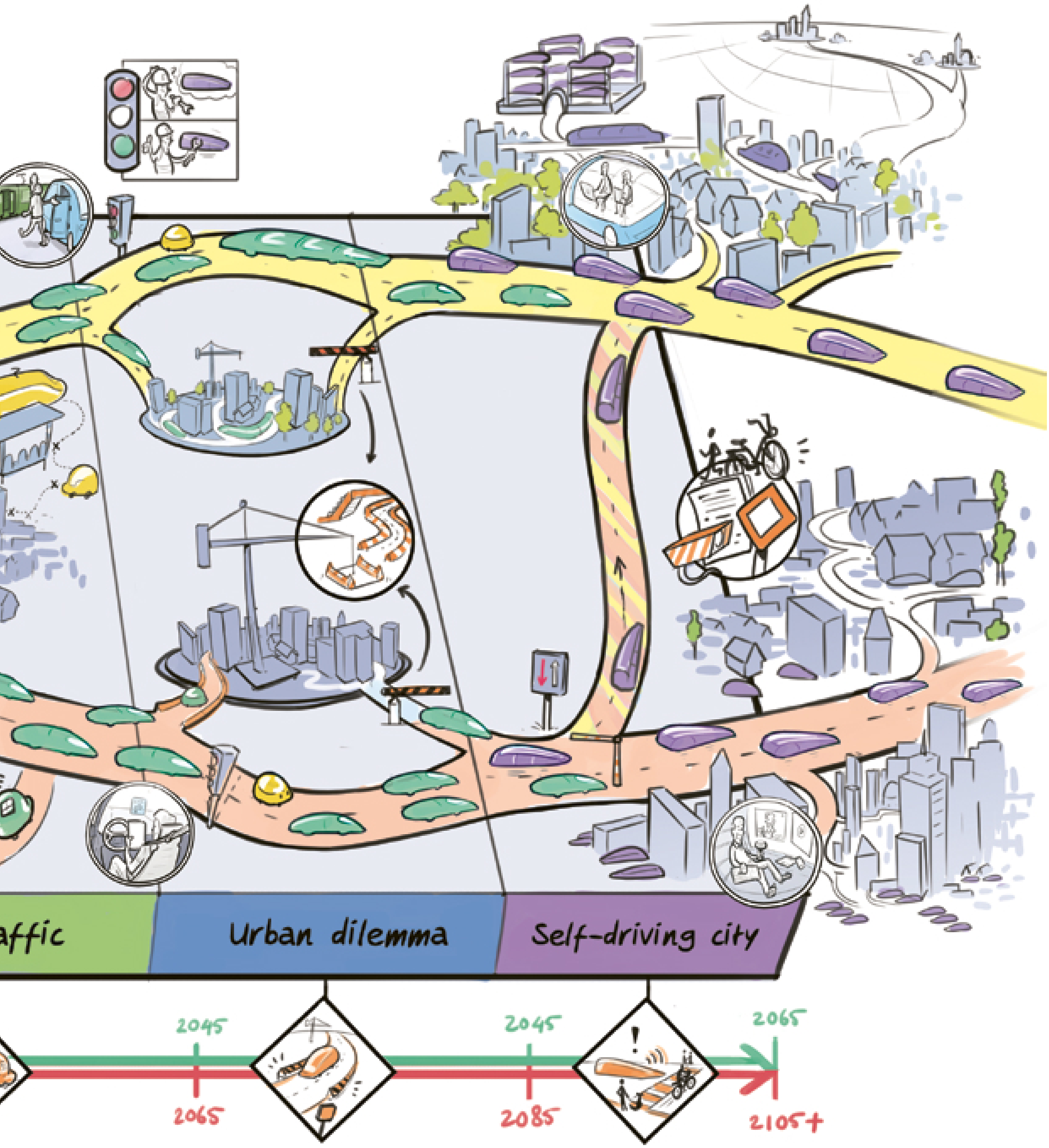
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Summary

A future in which self-driving cars define the traffic landscape: what will this look like and when could we expect this future to arrive, either solely on highways or everywhere? Great uncertainty surrounds these questions. If technological development is rapid, the technology affordable, self-driving cars attractive to car drivers and the societal impacts positive, a 'self-driving future' is highly probable. Policy measures moreover can accelerate this transition to a self-driving future. Concurrently, 'showstoppers' may emerge: developments that impede the transition.

The KiM Netherlands Institute for Transport Policy Analysis has devised two transition paths to a future traffic and transport system involving self-driving vehicles: 'Evolution of the private car' and 'Sharing in bloom'. 'Evolution of the private car' describes a transition in which most people still prefer to own their own vehicles, and the technological possibilities for self-driving vehicles increase step-by-step and gradually come onto the market. In the 'Sharing in bloom' transition path, the sharing of vehicles is commonplace. For both of these paths, how fast the transitions occur is a major uncertainty, and this will not only depend on technological developments, but also on how fast self-driving vehicles actually come onto the market and if they appeal to the public.

There are five steps on both transition paths in which an interplay of developments can profoundly impact the transition:
1. the interaction between man and machine;
2. cooperative or autonomous driving;
3. mixed traffic on the highway;
4. yes/no separating traffic streams in cities;
5. the 'self-driving city'.

Specific policy action points were mapped for each of these transition steps, and then divided into four categories: regulation and coordination; facilitation, execution and experimentation; conducting research; monitoring and evaluation. These action points are listed in a table on the booklet's back cover.

1
Introduction

A streetscape involving self-driving cars – still far off in the distant future or are we close? Seemingly every day media reports appear to support the latter scenario, yet, concurrently, many questions and uncertainties remain, including about safety. How these uncertainties are resolved, in combination with other developments, will ultimately determine if – and what type of – self-driving cars emerge and what this portends for future traffic and transport systems.

Decisive factors include what consumers will want and do, what models self-driving carmakers can and will make, and the extent to which governments facilitate and regulate developments. One factor cannot be separated from the others. Time dependency also comes into play: the path to the future is determined by choices and preferences in the here and now. Or, as Gandhi once said: *“The future depends on what you do today.”*

The importance of transition paths

What a future involving self-driving vehicles will look like is uncertain, and this also applies to the path for getting there. Learning to contend with uncertainties is an added value of reflecting on transition paths, which connect the present to future and reveal how certain developments could transpire and what this may depend on. Such reflection inspires analysts and policymakers, helping them to not only map the societal effects of self-driving vehicles, but also to make short- and medium-term (policy) choices that will limit or avoid any undesirable societal effects, while also boosting the desirable ones. Moreover, transition paths can identify key developments and 'sign posts', which are the parameters that reveal the direction developments are likely to go in, such as the consumers' preference for sharing vehicles, and consequently which developments are important to monitor for policy.

Future scenarios as the foundation for transition paths

In this study the KiM Netherlands Institute for Transport Policy Analysis presents two transition paths to a future traffic and transport system involving self-driving vehicles:

- Path 1: 'Evolution of the private car'
- Path 2: 'Sharing in bloom'

We used the four future scenarios described in the KiM report, *Driver at the wheel?* (KiM, 2015a), as the foundation for these transition paths. Multiple transition paths are detailed in the first stage, and then, following various review sessions, are reduced to their essential points.

The two paths collectively describe the key developments and uncertainties associated with transitioning to a future of self-driving vehicles, and in doing so they also identify the major policy action points.

Five key steps in the transition

We identified five key steps on the path from present to future in which an interplay of developments can profoundly impact the transition. These steps can help ensure a smooth transition; however, they may also encounter serious delays or take unexpected turns. The five transition steps from present to future are:

1. the interaction between man and machine;
2. cooperative or autonomous driving;
3. mixed traffic on the highway;
4. yes/no separating traffic streams in cities;
5. the 'self-driving city'.

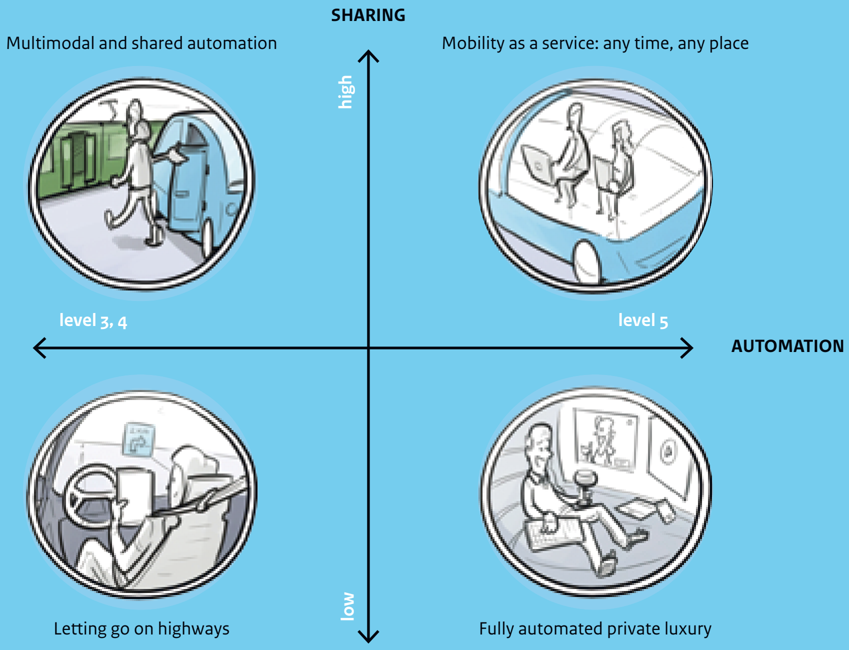
In this study we took a light-hearted approach to envisioning each of these steps as two opposing 'transition worlds'. These worlds show how a web of interrelated events, behaviours and preferences can lead to extremely different yet realistic outcomes. Unravelling this web provides action points for policy.

Driver at the wheel?

Self-driving cars can profoundly change our societies. Whether this will occur depends on the extent to which the car can function by itself (autonomously), as well as on what consumers want. Will cars become luxurious, mobile second homes or will drivers always be needed? The sharing economy is also an influential factor: if many people opt to share self-driving vehicles and rides, the traffic and transport system will be radically altered.

The KiM report, *Driver at the wheel?* (KiM, 2015a), describes four scenarios for a future traffic and transport system involving self-driving cars. These scenarios differ in degrees of acceptance and technology (exactly how 'automated' will self-driving cars actually be?), as well as the extent to which consumers will share (car ownership and rides). The figure below details these scenarios and the associated differences.

The images reveal that fully automated driving is not self-evident; rather, in two of the scenarios that stage is not reached at all, as drivers must maintain control of the steering wheel when driving in cities. The cars only fully take control of the driving tasks when on highways. Moreover, the report reveals that the extent to which people share vehicles and rides will profoundly impact the future complexion of society. If cars are capable of independently driving everywhere, and people remain committed to private car ownership, the streets will ultimately be filled with various brands of self-driving cars. And if the technology is so far advanced, it is also conceivable that people will use shared self-driving cars for every trip. Large companies will own the shared cars and park their vehicles on the outskirts of the city, which will considerably alter the streetscape.



Level of automation

What do we exactly mean by the terms self-driving or automated vehicles? The *Society of Automotive Engineers* distinguishes between six levels, ranging from 'no automation' (Level 0) to 'full automation' (Level 5) (SAE, 2016). In full automation, the car drives fully automatically on all roads and in every situation; moreover, the driver has become a passenger and need not take control of the vehicle in any situation (which is not yet possible).

The intermediate levels are characterized by increasing degrees of automation. In Levels 1 and 2 the driver must closely monitor the road, while starting in Level 3 the technology (conditional automation) assumes this task. Level 4 (high automation) has subsequently been reached when, in certain environments, such as on highways or in parking garages, the driver is absolutely no longer needed as 'back-up'.

Level	Description	Example	Role of driver
Human driver monitors the situation on the road			
0	No automation	Lane Departure Warning	Driver performs all driving tasks. Driver-support systems are possible.
1	Driver assistance	Adaptive Cruise Control	The car can perform some driving task (for example, maintaining following distances). The driver monitors the situation and performs other driving tasks.
2	Partial automation	Parking Assistance	The car can self-navigate (for example on highways). The driver continuously monitors the situation.
The automated system monitors the situation on the road			
3	Conditional automation	Highway Chauffeur	In certain situations (on highways for example), the driver can engage in other activities (reading, Skyping), but must intervene/take over if the system requires it ('fallback-ready user').
4	High automation	Highway Chauffeur, Parking Garage Pilot	Driver can engage in other activities, even sleep, in all situations (for example on the highways).
5	Full automation	Robot Taxi	No driver required.

Sharing economy

A car remains unused for large parts of the day; consequently, inefficient use and large overcapacity prevail, and this not only applies to cars but also to many other personal possessions, like tools, campers or party tents. Such unused capacity serves as the foundation of the sharing economy, in which online platforms are developed to facilitate sharing, often involving financial compensation.

Car sharing is on the rise. In 2014, there were some 5 million car sharers and more than 100,000 shared cars worldwide. These are still marginal figures, but given the steady growth in shared car users and providers, interest is seemingly set to continue rising. We distinguish between two types of sharing: the sharing of cars, and the sharing of car rides (with multiple people travelling together in one car).

2
Transition paths to a future involving self-driving vehicles

In this chapter we present two transition paths to a future involving self-driving vehicles. The ‘Evolution of the private car’ path describes a gradual transition in which most people still prefer to own their own vehicles; they will only share the vehicles within their own households. In the ‘Sharing in bloom’ transition path, vehicle sharing – both ownership and use – is flourishing.

Reader’s guide to the transition paths

Two transition paths are outlined on this booklet’s cover flap:

- Path 1: ‘Evolution of the private car’
- Path 2: ‘Sharing in bloom’

The foundation for these transition paths are the four future scenarios in KiM’s report, *Driver at the wheel?* (KiM, 2015a):

- *Letting go on highways;*
- *Fully automated private luxury;*
- *Multimodal and shared automation;*
- *Mobility as a service: any time, any place.*

Both transition paths begin in the present (left) and end in the future (right). We observe that the short-term developments in both transition paths are identical. We identify five key steps on the path between present and future in which an interplay of developments can profoundly impact the transition (both positively and negatively). We examine these transition steps in greater detail in the following chapters: Man and machine (Chapter 3); Cooperative driving (Chapter 4); Mixed traffic on the highway (Chapter 5); Urban dilemma (Chapter 6); and Self-driving city (Chapter 7).

The technological possibilities of self-driving cars increase as we proceed from one step to the next (from level 0 to level 5). A new self-driving vehicle immediately joins the traffic stream as soon as it comes onto the market. This ensures that, except for in the beginning (level 0) and the end (level 5) of the transition, there are always stages in which vehicles of differing automation levels are simultaneously present in the traffic stream.

Fast vs slow transition

The speed at which the transition occurs is one of the greatest uncertainties: this will not only depend on the rate of technological development, but also on how accepting the public is of self-driving vehicles, and how fast the sales thereof will dominate (‘market penetration’). The penetration will be faster if purchase prices rapidly fall and older vehicles can be easily and inexpensively adapted with upgraded software, for example.

In order to properly address these uncertainties, we distinguish between a fast and slow transition. On the fast path only level 3-4 vehicles are only occasionaly seen on the roads in 2025, with these vehicles having come onto the market a few years earlier. It will then take around two decades before the vast majority of self-driving vehicles can autonomously drive on highways (the future scenarios, *Letting go on highways* or *Multimodal and shared automation*). Level 5 vehicles will also come onto the market at this time, and if they also function well within the total urban transport system, the development will proceed and some 20 years later we arrive in the world of *Fully automated private luxury or Mobility as a service: any time, any place*. By then it will be the year 2065.

In the slower transition, it is more the technological development, and less the penetration in the traffic flow, that proceeds more slowly. Vehicles from levels 3-4 will only emerge with any regularity some 20 years later (2045). Level 5 will also become possible at a later date (2085), and level 3-4 will serve as the standard for a longer period of time. We will not arrive in the world of *Fully automated private luxury of Mobility as a service: any time, any place* until 2100.

In this study we combined levels 3 and 4, as it is possible to drive fully automatically in both levels in certain situations, such as on highways. The car drives itself and automatically monitors the surroundings; the driver meanwhile can devote his ‘highway travel time’ to other pursuits, such as reading, Skyping and gaming. The only difference is that in level 3, the driver must in some cases take over the driving tasks if the vehicle requires it (‘*fallback-ready user*’; SAE, 2016). In level 4 the technology solves any problems that may arise (on the highway). There is some question however as to whether level 3 can occur safely in practice, as a certain amount of time (multiple seconds) is required before the driver, who is engaged in other pursuits (for example, reading; ‘*out the loop*’), can get his hands back on the steering wheel and regain a proper overview of the road (‘*in the loop*’).

Path 1: Evolution of the private car

The first transition path, 'Evolution of the private car', describes a gradual transition to a self-driving future, in which most people still prefer to own their own vehicles. In this section we describe the three stages in this path: 'level 1-2, cooperative driving, experimentation and upscaling'; 'from level 3-4 as technological possibilities to Letting go on highways'; and 'from Letting go on highways to Fully automated private luxury'.

Levels 1-2, cooperative driving, experimentation and upscaling

Between now and 2025/2045 (depending on a fast or slow transition), we identify five developments that are partly independent of each other, partly successive, and partly overlapping:

1. the penetration of driver-supported systems;
2. the penetration of connected/cooperative technology;
3. experimentation with automation levels that only come into bloom in the longer term;
4. from experimentation to upscaling;
5. rendering cooperative driving possible on a large scale.

1. The penetration of driver-supported systems
With this development, increasingly more vehicles are equipped with smart systems in and around the vehicle that help drivers get from A to B more easily, safely and sustainably. These are systems that 'unburden' the driver ('driver support systems'), such as navigation and fatigue recognition systems, as well as those that assist the vehicle ('vehicle support systems'), such as speed control and 'lane departure warnings' (Kyriadis *et al.*, 2015). As smart technology continues to develop, the use of 'connected' technology will increase, for example via Wi-Fi(-p) or mobile phone networks.

Step 1: Penetration of smart informing, advising and warning systems (level 0)
In the first instance, systems that inform and advise will become increasingly common. These systems – navigation systems being a common example – help facilitate and accelerate trips. Other such unburdening systems include traffic information sign recognition, Night View Assist, blind corner information assistants and intelligent speed advisories (see also Timmer & Kool, 2014). Such systems primarily focus on improving traffic safety; moreover, they belong to level 0 automation ('no automation'), because a person must still perform all driving tasks.

Current situation:
Penetration of navigation systems

Nine out of every ten Dutch car drivers currently have a navigation system within their households, of which approximately 40 percent are 'connected' and provide traffic information (KiM, 2015b); they are either built into the vehicle or 'nomadic' (like TomTom, for example). Further, increasingly more people use navigation-apps for smartphones or tablets.

Step 2: Penetration of smart systems that take over certain driving tasks (level 1-2)
A next step is to equip increasingly more vehicles with systems that take over driving tasks under certain conditions, examples of which include Adaptive Cruise Control (ACC), Lane Keeping Assist, Intelligent Speed Adaptation (ISA) and emergency braking systems. These systems are primarily focused on improving traffic safety, but can also positively impact the environment (specifically ACC and ISA). These ACC-systems are not yet cooperative (C-ACC).

Current situation: Sales of smart systems

Less than five years ago only around 5 percent of cars newly registered in the EU were equipped with smart driver-support systems ('adaptive headlights', at 13 percent, are an exception). This figure will increase if the Euro NCAP-safety test begins including such systems in vehicle safety ratings (Kyriadis *et al.*, 2015). In 2012, only 4 percent of newly registered vehicles in the Netherlands had ACC, which is a higher percentage than the EU28 average (3.1 percent), yet lower than the EU's leader, Germany (at nearly 7 percent) (Kyriadis *et al.*, 2015).

Current situation: Cooperative technology

No cars currently on the market can really communicate with each other or the road, although such initiatives exist: in 2016, the 28 EU countries signed the *Declaration of Amsterdam*, reaching agreement on the steps required for allowing self-driving technology to develop in the EU. Cooperative driving plays a key role in this. Similarly, Talking Traffic is one such Dutch initiative, in which a collective of service-providing market parties strive to implement cooperative ITS-initiatives that will result in rapid road traffic flows (ITS: intelligent transport systems).

2. The penetration of connected/cooperative technology

Cooperative, or connected, technology allows vehicles to communicate with each other (vehicle-to-vehicle), with roadside infrastructure (vehicle-to-infrastructure) or with clouds (vehicle-to-cloud), thereby allowing vehicles to drive closer behind one another, as each vehicle knows precisely what the other will do. The expectation is that this will not only result in fewer traffic incidents, but also in shorter travel times (less congestion) and improved traffic safety and air quality. For cooperative driving, the focal points are privacy-related issues, the ownership of data and the protection thereof.

3. Experimentation with automation levels

Experiments with self-driving technology are also conducted in this shorter term stage, although the technology will only come onto the market in the longer term. With an eye towards future market introduction, the aim is to learn from these pilot projects.

Current situation: Experimentation

Experiments of many types and scales are being conducted, pertaining to passenger cars, the automation of public transport and freight transport via road. Specific examples of experiments conducted in the Netherlands and abroad include:

- **Passenger cars:** In 2017, the Drive Me-pilot project will start in Göteborg, Sweden, involving hundreds of self-driving Volvo's. This experiment will focus on level 3 vehicles ('conditional automation'); on select routes, drivers will relinquish control of the driving tasks.

- **Public Transportation:** A well-known example in the Netherlands is the Wepod-experiment in Gelderland: in 2016, a self-driving pod (level 3-4; 'conditional/high automation') drove on the Wageningen University campus. Further, the 'CityMobil2' experiment was conducted on the European level.
- **Trucks:** The 'European Truck Platooning Challenge' was held in 2016: various manufacturers' trucks drove behind each other autonomously in 'truck-train' formations to Rotterdam. The trucks did have drivers in them, however.

4. From experimentation to upscaling
The experiments described in point 3 were small-scale. A gradual upscaling of experiments will occur during this stage, marking a crucial intermediate step toward large-scale market introduction. Experiments are conducted under controlled conditions (on reserved routes and lanes) to determine how large numbers of self-driving vehicles behave in traffic flows with other, non-automated traffic.

This stage also sees the automated systems for public transportation gradually upscaled: examples would include the implementation of small automated buses ('*pods*') as '*last mile*' transportation, and the automation of trams and metros on separated trajectories; in fact, this pertains to a level 4 system, which is easier to automate with own infrastructure than the car.

5. Rendering cooperative driving possible on a large scale
In this stage, investments are made in the hardware and software required for allowing information to be exchanged with the surrounding environment. This could possibly occur in stages: first on highways, and later on all other key roads outside of cities. Vehicles are equipped with systems that allow them to communicate with each other seamlessly and in the same language ('*vehicle-to-vehicle*') when on highways and other main non-urban thoroughfares, and to exchange information with systems situated outside of the vehicles, as it pertains to congestion and road accidents, for example. Such communication can occur via physical infrastructure (portals and small cabinets) along the road ('*vehicle-to-infrastructure*'), or via clouds ('*vehicle-to-cloud*'). Over time, cloud systems should ultimately be able to completely replace the expensive roadside systems.

To avoid horrifying scenes of massive accidents, it is essential that the data and systems are secure and protected against disruptions and cyber-attacks. Moreover, good fall back options ('*redundancy*') must exist, such as double-secured (back-up) systems that allow vehicles to continue driving during disruptions, and measures to ensure that the vehicles can come safely to a stop.

It is crucial that sufficient data space be available at all times. Strict agreements must be reached if the mobile network capacity will also be used for other purposes (mobile internet, for example). Finally, attention must be given to software development and standardisation.

From level 3-4 as technological possibilities to 'Letting go on highways'
For the period between 2025/2045 and 2045/2065 (depending on a fast or slow transition), we identify two successive stages in the 'Evolution of the private car' path:
1. Mixed traffic: a mix of manual and autonomous vehicles outside of cities.
2. *Letting go on highways.*

1. Mixed traffic: a mix of manual and level 3-4 vehicles outside of cities

After a slow start, the number of passenger cars equipped with advanced cooperative systems (level 1 and 2; C-ACC, autopilot) will rapidly increase during this stage of the transition. Cars in the small mid-range class will also be summarily equipped.

The penetration will progress faster for trucks, and '*platoons*' – automated trucks driving in convoys on highways – are now commonplace. This more rapid penetration for trucks is partly due to their shorter amortization periods and the cost advantages afforded by fuel efficiency. Public transportation companies have also invested in making their fleets cooperative.

This stage sees the number of roads where driving automatically is possible expanded step-by-step: initially only on highways (minimum 2x2 lanes), and later on other roads outside of cities (particularly 2x1 lanes). The digital infrastructure (roadside and/or cloud systems) is also rolled out during this stage. Owing to safety considerations, highways have priority: highways have physically separated lanes, unlike other main roads outside of cities.

Trucks only 'platoon' on highways. Platoon-forming is difficult to achieve on other roads outside of cities, owing to the presence of non-automated cars and buses.

Current situation: Effects of automated cooperative vehicles (level 1-2)

In this stage, automated vehicles have perceptible effects on traffic flows and safety. A market penetration of around 10 percent can already reduce traffic congestion on highways by 15 percent (Fagnant & Kockelman, 2015), and that reduction will be larger if older, less advanced vehicles are more rapidly removed from the car fleet. However, these are high quality cars with long lifespans; hence, at this stage, companies will emerge to 'update' these 'dumber' cars. It is expected to take quite some time before such cars are completely phased out.

In this stage the various automakers start offering level 3-4 systems in their premium models; consequently, drivers no longer need to drive their cars themselves outside of cities: the technology takes over all driving tasks. Drivers can now devote their 'highway drive time' to other pursuits, like reading, Skyping and gaming. The vehicle uses its in-built cooperative technology for *vehicle-to-infrastructure* (V2I) and *vehicle-to-cloud* (V2C). Level 3-4 vehicle technologies are expected to become increasingly less expensive. Consequently, sales of new vehicles with level 1-2 technologies will gradually decline.

This transition stage is characterised by a mixture of vehicles with varying automation levels. This stage could last for a considerable period of time – perhaps a couple decades.

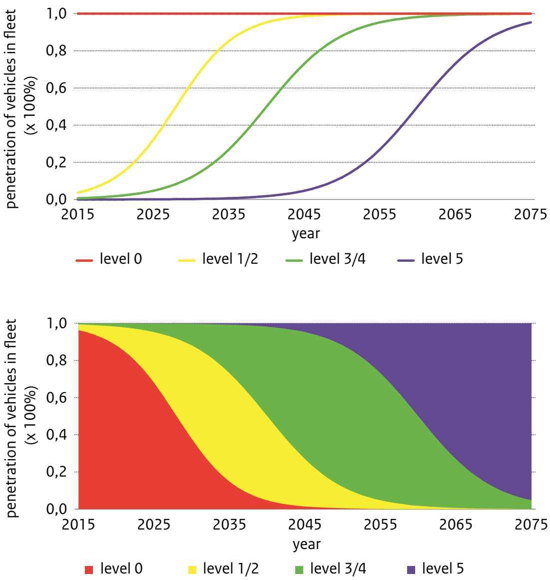
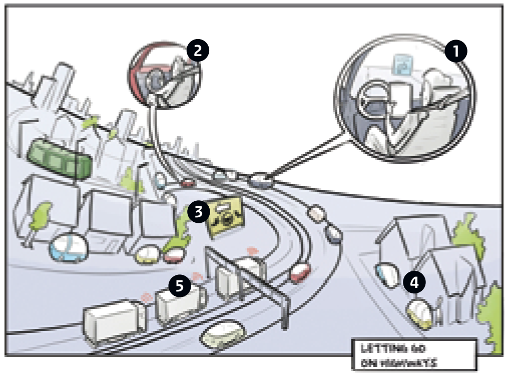


Figure *'Mixed traffic'; (hypothetical) illustration of the technological feasibility of automation levels and time periods for penetration in the traffic streams*

2. 'Letting go on highways'

Now that more automated vehicles (level 3-4) are on the roads, and the less advanced vehicles are gradually being phased out, we have arrived at the *Letting go on highways* future scenario. As facilitated by the government, the national and provincial roads now enjoy relatively high levels of automation. A significant minority of car drivers still prefer to have their hands on the steering wheel. Car drivers must drive their cars in the cities, where we also find reliable public transportation. Trams and metros continue to perform an important function, although, owing to separated lanes, they no longer require drivers. Buses remain operational to a limited degree. Additionally, in some cities, a limited number of automated pods operate on fixed routes as *'last mile'* transportation to and from stations. *The Letting go on highways* future scenario is described in the report, *'Driver at the wheel?* (KiM, 2015a). The key characteristics are:



General overview
- 'Hands free' on highways (level 3-4) for many people **(1)**
- 'Hands on the steering wheel' in the city; but also support systems (level 1) **(2)**
- 'Transition zone' needed for highway to city **(3)**
- Automated parallel parking in parking garages
- Cars parked outside the door **(4)**
- Platoons on highways; resting drivers **(5)**

Societal effects
- Traffic flow: possible slight decrease due to increased car use
- Traffic safety: increases primarily in non-urban areas (among car passengers)
- Environment and liveability: slightly negative effects possible due to increased car use
- Effective use of time: on highways/outside of cities; possibly longer (home-to-work) commuting distances

From 'Letting go on highways' to 'Fully automated private luxury'

As the development continues, we observe two stages occurring in this transition path over the longer term (from 2045/2065 to 2065/2100+), which are partly successive and partly overlapping:
1. The bridge between levels 3-4 and 5.
2. *Fully automated private luxury.*

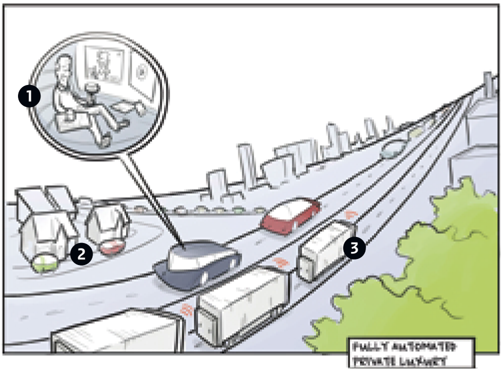
1. The bridge between levels 3-4 and 5

It remains uncertain whether a step from level 3-4 to level 5 is feasible, especially given the uncertainties surrounding the technological developments. It is a huge leap from level 3-4, when cars safely drive automatically on highways, to level 5, when cars drive fully automatically everywhere and always. According to Shladover (2016), level 5 will not be reached until around 2075. Level 4 will serve as the standard in intervening decades.

Governments can do two things during that intervening period:
- do nothing and wait for level 5 to come onto the market by itself;
- expand the (road)infrastructure that level 3-4 operates on, for example on certain routes within cities.

If governments do not want to wait longer for level 5 to arrive, they can choose the second option. Governments can render infrastructure suitable for automated driving on certain routes within cities, and consequently also capitalise on the positive effects that level 4 has on traffic flows and the time spent by car drivers. This can be done by physically separating car and bicycle traffic and reducing the number of intersections; for example, transition zones will be created for transitioning from automated to non-automated driving within cities, with drivers receiving signals informing them that they must now retake control of the steering.

2. Level 5 and 'Fully automated private luxury'
Level 5 vehicles have come onto the market in this stage. Initially, however, they are only for *early adopters* who can afford the high initial purchase prices. Subsequently, the number of fully automated vehicles (level 5) will sharply increase, as the less advanced vehicles are gradually phased out. We have now arrived in the world of *Fully automated private luxury*. The self-driving car is equipped with various amenities and fully customised according to the owners' wishes. This future scenario is also detailed in the report, *Driver at the wheel?* (KiM, 2015a). The key characteristics are:



AGeneral overview
- 'Fully connected' cocoon, no steering wheel **(1)**
- Sharing only among household members
- Traditional public transportation has largely disappeared
- Uber-like system for people who do not own cars
- Cars are parked outside the door **(2)**
- People purchase their cars from car dealerships
- Platoons on highways; no truck cab/driver **(3)**

Societal effects
- Traffic flow: possible decrease due to increased car use
- Traffic safety: increases everywhere (among car passengers)
- Environment and liveability: possible negative effects due to increased car use
- Social inclusion: increases for handicapped people, children and senior citizens
- Effective use of time: everywhere; possible longer (home-to-work) commuting distances

Pad 2: Sharing in bloom

In the second transition path – 'Sharing in bloom' – car sharing is entirely self-evident; consequently, both car ownership and car use are shared. This path consists of three stages, which we examine closely in the following section.

Level 1-2, cooperative driving, experimentation and upscaling

The short term developments in the 'Sharing in bloom' transition path are the same as those in the 'Evolution of the private car' transition path.

**Current situation:
Present state of 'sharing'**

Car sharing is increasing, but presently the number of car sharers and shared cars remains marginal. Approximately 1 percent of Dutch people aged 18 and older use one or more types of car sharing. These people are usually highly educated, do not own cars, and reside in cities. Moreover, the use is not equally divided across the Netherlands; rather, it remains primarily concentrated among residents of urban areas, such as Amsterdam and Utrecht (KiM, 2015c). Because the extent to which this technology will develop remains unclear, it is also uncertain whether the sharing of car ownership and car rides (with multiple people riding in one car) will really take off.

From level 3-4 as technological possibility to 'Multimodal and shared automation'

The sharing economy is flourishing in this transition path (even before level 3-4 vehicle automation is technologically possible). Sharing goods and services is now the most common thing to do in the world, and this also applies to sharing car ownership and car rides. Sharing saves money and makes society more liveable and sustainable.

The technological development and possibilities afforded by automated driving are the same as those in the 'Evolution of the private car' transition path. The paths differ in that automated public transportation and sharing systems are used more in the 'vehicle-sharing path'.

Four different developments occur simultaneously in this path:
1. upscaling of automated public transportation systems;
2. use of automated pods for the 'last mile' transportation;
3. use of automated shared cars outside of cities;
4. Continued growth towards *Multimodal and shared automation*.

1. Upscaling of automated public transportation systems

Governments and transport companies are focused on the large-scale automation of public transportation systems, with the objective being to enhance the liveability of cities. Information and communication technologies allow for high frequency public transport. A digital real-time-travel assistant supports public transport passengers from door-to-door. Increasing numbers of driverless trams and metros travel on separate trajectories, which reduces costs. Moreover, ticket processing and checking is further automated. The system is monitored from a main transport centre, where, if necessary, they can also take control of the trams and metros.

2. Use of automated pods for the 'last mile'

(Local) governments and transport companies have seized upon the technological progress for further automating the *'last mile'* transport:
- Automated, driverless pod-/bus-systems operate in an increasing number of *cities*, driving (initially at relatively low speed) on fixed routes between main public transportation hubs, such as stations and key destinations, including city centres and university campuses.

- Such vehicles also operate in some *outlying* areas. This occurs on a limited number of easy-to-automate routes where traditional, manned public transportation is under pressure or has already disappeared. Consequently, the viability and accessibility of services is guaranteed.

3. Use of automated shared cars outside of the city

Significant numbers of people still have access to (lease) cars. Concurrently, car sharing remains in ascendency: numerous shared cars are parked on virtually every street, while car sharing providers ('fleet administrators') and platforms (like Uber and Lyft) compete on price and quality. Some people privately share their cars. The shared vehicle is used for both short and long distance trips.

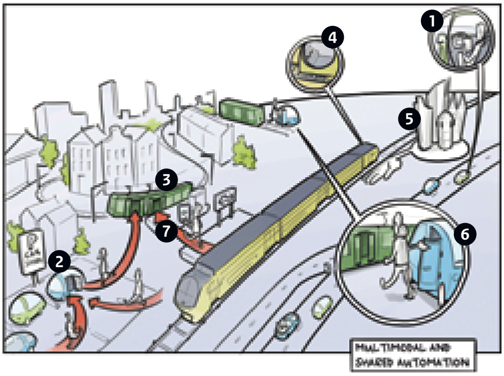
Additionally, shared cars are increasingly part of an integrated, multimodal transport system. Users can pick up or drop off their shared cars at Park&Ride lots situated at key public transport hubs. The cars autonomously search for parking lots designated for shared cars. This development is facilitated by the emergence of fully integrated payment systems.

Fully automated door-to-door transport is not yet possible at this stage, as shared cars are only permitted to drive automatically on roads outside of cities (level 3-4). In the city, drivers must take control of the wheel. Rides are primarily shared among family members, relatives and friends – not with strangers.

Automated vehicles are more rapidly penetrating the car fleet in this transition path than in the 'Evolution of the private car' path. Because shared cars are used intensively, they depreciate faster, which could in turn also accelerate the innovation of self-driving vehicles. For fleet administrators, efficiency is a reason to invest in automated vehicles: because these vehicles have superior driving characteristics, they suffer less damage and hence have lower maintenance costs.

4. 'Multimodal and shared automation'

Car sharing has become commonplace, with increasingly fewer people continuing to own cars. The technology is not yet sufficiently developed, and the support too limited, for fully automated driving (in cities). Virtually every city has invested heavily in the automation of public transport. We have arrived in the world of *Multimodal and shared automation*. This future scenario is detailed in the report, Driver at the wheel? (KiM, 2015a). The key characteristics are:



General overview
- 'Hands free' on the highway (level 3-4) for many people **(1)**
- High degree of sharing (car ownership and rides) **(2)**
- Public transportation is popular due to preference for sharing **(3)**
- Driverless trains/trams/metro's and high frequencies. Also automated pods on a number of fixed routes **(4)**
- Government promotes large-scale public transportation in cities **(5)**
- Efficient multi-modal trips and changes between modes **(6)**
- Digital travel assistant supports trip **(7)**

Societal effects
- Traffic flow: possible improvement due to increased sharing
- Traffic safety: particularly increases outside of cities (among car passengers)
- Environment and liveability: likely minor positive effects due to increased car sharing and public transport use
- Effective use of time: on highways/outside of cities and in public transportation; possibly longer (home-to-work) commuting distances

From ‘Multimodal and shared automation’ to ‘Mobility as a service: any time, any place’

As the development toward level 5 continues in the ‘vehicle-sharing path’, we observe three long-term stages that are partly successive and partly overlapping:

1. bridge between levels 4 and 5.
2. level 5 (full automation): automated driving in and outside of cities.
3. continued growth toward *Mobility as a service: any time any place*.

1. Bridge between levels 4 and 5

Here the same two options come into play as in the ‘Evolution of the private car’ transition path: if it will take a long time until level 5 is feasible, the government faces the choice of (temporarily) doing nothing or extending the possibilities afforded by level 3-4’s self-driving ‘highway car’ to other roads.

2. Level 5: automated driving in and outside of cities

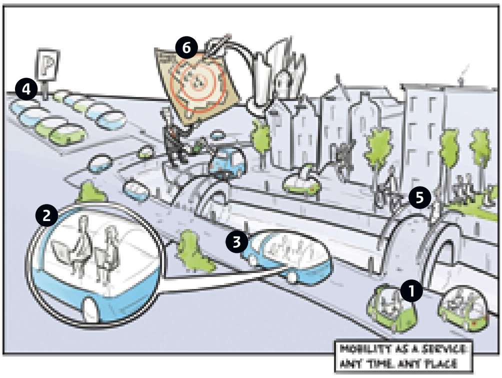
The market is full of fully automated vehicles at this stage. Shared car providers purchase these vehicles and gradually phase out their less-advanced vehicles (level 3-4). Level 5 vehicles’ penetration in the car fleet occurs more rapidly than in the other transition path, because shared cars are used relatively intensively and hence depreciate quickly.

Sharing companies invest in various concepts; some focus on luxury shared cars, in which a person usually rides alone, while others offer less expensive, simpler services for getting from A to B, in which both the vehicles and rides are shared.

The more traditional public transportation is under pressure, owing to the greater ease and comfort that fully automated cars offer and the possibility of arranging small-scale automated door-to-door transport. Bus line services are not only increasingly disappearing, but automated tram services are also facing difficulties. Only the ‘heavy flow’ scheduled services, like metros and (high-speed) trains, continue to flourish.

3. Mobility as a service: any time, any place

The technology has developed to level 5 and most vehicles drive fully automatically. People are very willing to share their transport modes. Mobility is a service, and self-driving cars are available always and everywhere. This future scenario – *Mobility as a service: any time, any place* – is detailed in the report, Driver at the wheel? (KiM, 2015a). The key characteristics are:



General overview

- Door to door travel via automated people movers **(1)**
- The sharing economy flourishes (car ownership and rides) **(2)**
- Disappearance of (most) traditional public transportation **(3)**
- Cars park themselves in parking areas situated at the outskirts of the city **(4)**
- People opt to walk and cycle whenever possible **(5)**
- Price/km within the city increases **(6)**

- *Societal effects*
- Traffic flow: possible slight improvement due to increased sharing
- Traffic safety: increases everywhere (among car passengers)
- Environment and liveability: possible positive effects due to high degree of sharing
- Social inclusion: increases for handicapped people, children and senior citizens
- Effective use of time: everywhere; possibly longer (home-to-work) commuting distances

From one path to the other: from not sharing to sharing

In the 'Evolution of the private car' path, the sharing of cars and rides is not commonplace in the short- and medium-term, because most people value convenient and comfortable door-to-door transportation. Shared cars must first be reserved, and moreover they are not parked outside one's door, as privately owned cars often are. Ride sharing is also deemed impractical: a driver is always required, as the cars can only drive automatically on highways, not in cities. Many people therefore prefer to have a 'private car', which they own or lease. Sharing remains synonymous with public transportation.

If level 5 proves feasible, the 'Evolution of the private car' path will further develop in the direction of *Fully automated private luxury*. The one-direction connecting roads in the 'Self-driving city' stage illustrate this potential transition. Because level 5 allows for less expensive shared door-to-door transportation, a (partial) shift to the 'Sharing in bloom' transition path could occur. While the large traditional automakers are focused on developing all types of automated passenger cars and primarily compete on luxury, newcomers to the market could concentrate on developing and marketing more austere, 'functional' fully automated pods that provide inexpensive, shared door-to-door transportation. This system could initially appeal to young people and people on tight budgets, for example. Thereafter, other types of automated pods will come onto the market, including those with small, separate private compartments that target consumers who place great value on privacy. A (partial) shift to the world of *Mobility as a service: any time, any place* has now occurred.

Five steps identified

Whether a transition to self-driving vehicles occurs in future depends on uncertain developments. What people want and do is important, as is how self-driving carmakers can and will manufacture the cars, and the extent to which governments facilitate and regulate developments. One is not separate from the other. Will people want to ride in self-driving cars? And what is the situation concerning the ownership, use and sharing of information and data? To what extent do people want to share cars? Are carmakers capable of developing cars that allow people and technology to optimally support one another? Or, to take this a step further: is it even possible to make fully automated vehicles that can safely drive automatically everywhere and always?

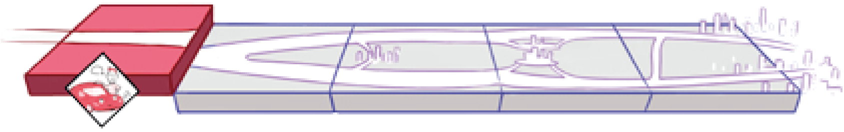
We identified five key steps on the path from present to future in which an interplay of developments could profoundly impact the transition. These steps from present to future are:

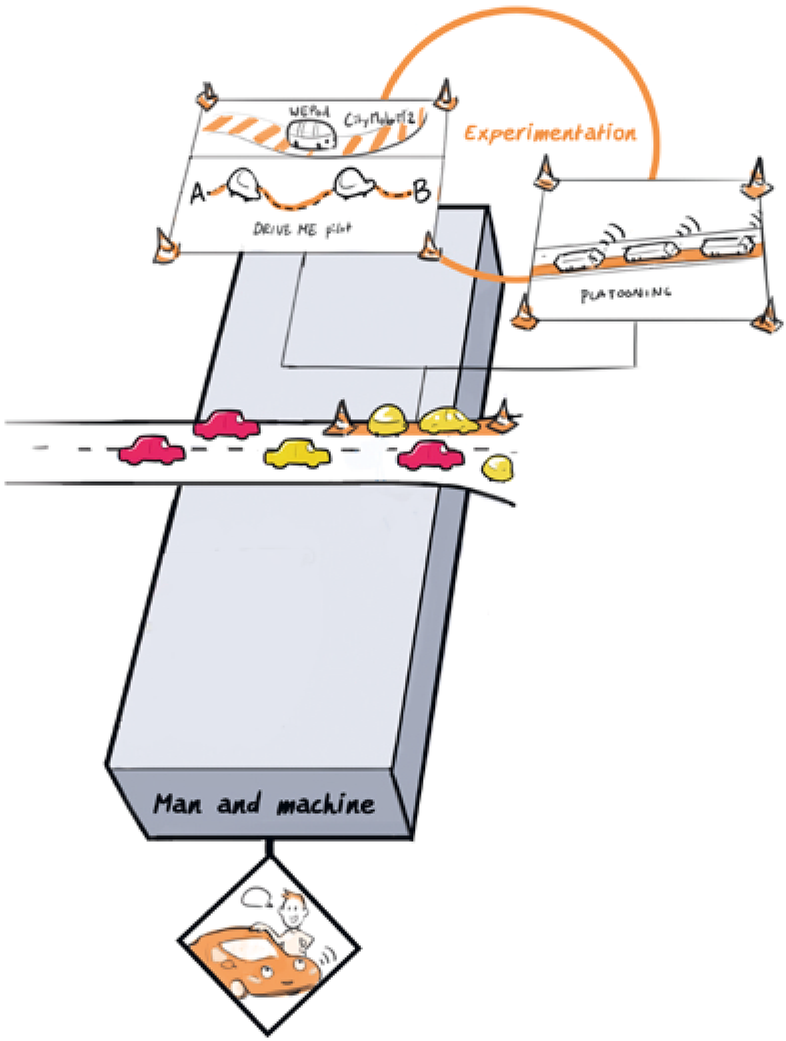
1. Man and machine: the best of both worlds or not?
2. Cooperative driving: holy grail or a bridge too far?
3. Mixed traffic on the highway: solvable or showstopper?
4. Urban dilemma: do nothing or separate traffic streams?
5. Self-driving city: harmonious interaction or contested ground?

We identified the policy action points for each of these transition steps, and then divided them into the following four categories:

- regulation and coordination;
- facilitation, execution and experimentation;
- conducting research;
- monitoring and evaluation

A complete overview of the policy action points during the transition are listed in a table on the back cover.

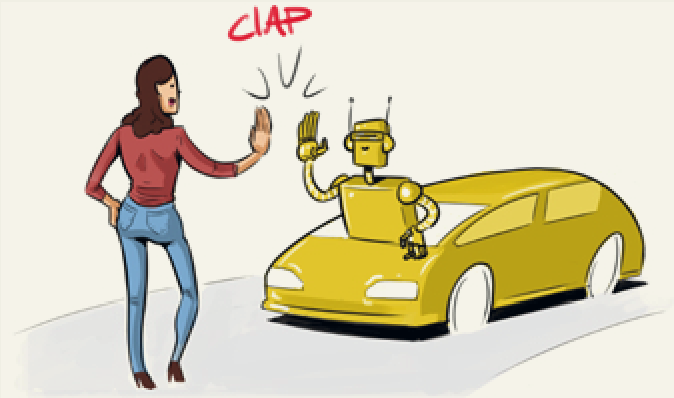



WEPod
A
B
Experimentation
PLATOONING
Man and machine

3
Man and machine: the best of both worlds or not?

When we talk about automated or self-driving cars, we often envision futuristic cars, like Google's autopod or the Mercedes F 015, in which we no longer have to do anything ourselves and can instead relax or work. Such technology does not yet exist. Before progressing so far, a transition period is likely, when vehicles equipped with advanced steering support systems will take over the various driving tasks, particularly on highways. The driver must remain actively alert. The *interaction between people and the vehicle* will play a crucial role during this transition stage. We describe two scenarios in this chapter: in one the vehicle and person complement and support one other, while in the other the human and machine interact poorly.

Digital Daily Telegraph (DDT), 14 April, 2022



The machine cannot yet do without the man

By our editorial staff

Yesterday the German carmaker, *Volksstrom*, launched the Amigo Volta, while last week saw China's *General Car Industries* introduce the new Avanti on the market. Both cars feature the latest adaptive cruise control, complemented by a system that allows the cars to automatedly change lanes. Even though these systems represent the height of technological ingenuity, they nevertheless remain far from the ideal of a fully self-driving car. Expectations were high in years 2010 to 2020: the dream was for a car with no steering wheel and pedals, in which passengers no longer had to do anything. Meanwhile, the optimists have been rudely awakened from their self-driving-car-dream. We look back and to the future with Professor Marieke Broekhuizen, an expert in semi-self-driving cars at Delft University of Technology's Automotive Institute.

At the time did you believe in a fully self-driving car?

"I must admit that back in 2016, 2017… I did think a fully self-driving car would quickly arrive on the market. And I wasn't alone, everyone was optimistic. The technology was progressing by leaps and bounds and the first test results were extremely positive. However, after a few years, we all had our feet back on the ground. Developing cars 'that can do everything' simply proved more complicated than expected. Machines usually make fewer mistakes than people, but traffic is a major exception to that rule. People are just really good at driving, and if you express this in vehicle hours, you'll see that there's a fatal accident only about once every few hundred years. People are much better at dealing with the complex, unexpected situations on the road than technology is. The machine cannot yet do without the man."

Have traffic accidents also contributed to the image of self-driving cars?

"Oh, definitely… the system's limitations were harshly, even tragically, exposed in recent years. All manner of unsafe situations arose during the test stages – there were even fatalities. Consequently, it's perfectly reasonable that consumers were wary. The trust was gone. They no longer wanted to relinquish control of the steering wheel."

Where do we stand now?

"We know that technology can support humans, but that's not yet the same thing as taking over all human tasks. People and technology must complement one another in the coming years. Two can see and do more than one. People are good at coordinating and improvising, and technology is good at recording and reacting. We must combine the best of both worlds. Man and machine are currently working excellently together. The separation that was made between highways and cities was also wise. The *highway pilot* works great on the highway: you automatically follow the vehicle in front of you, the proper distance is maintained and your car automatically switches lanes. That's wonderful, keep it like it is, but the person is still needed. I notice this myself when I'm in my car: you must constantly monitor your surroundings. And this is especially true when driving in the city: you have to keep control, although the new emergency braking and detection systems for cyclists and pedestrians are indeed a welcome addition."

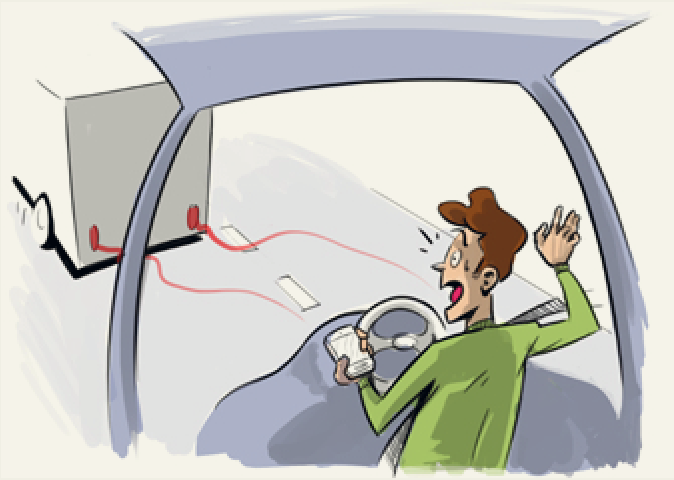
Will there ever be a fully self-driving car?

"It's certainly not impossible, especially on the highways, but it will take a few more years. The car industry is now playing a waiting game. The technology must be further developed, and with the current support systems, there is enough profit to go around. I know they are currently working on systems that allow cars to drive independently outside of cities. I also believe that this will be possible over time, and that consumers will see the value in it. If you are able to do other things while riding in a self-driving vehicle, like read a book or take a nap or work, such cars could be very appealing some day. "

And if the Ministry of Infrastructure and the Environment should intervene? A fully self-driving car is still safer and better for traffic flows?

"I really don't see the government vigorously pursuing this in the short term. The current systems have already succeeded in achieving some of the policy goals; it is now much safer in the cities and on the highways, as the latest statistics clearly show. The traffic flow has also improved, and we can now drive closer together than ever before on the highway, which has also had positive effects for the environment. Indeed, the progress is slow, and perhaps in the Minister's eyes a bit too slow, but the expectations are that in terms of safety, traffic flow and the environment, the desired gains will be made in the years ahead. The combination of man and machine: for policy, this currently represents the best of both worlds. The only changes I could foresee coming would be if policy focused more on other benefits offered by self-driving cars, like the effective use of travel time."

Digital Daily Telegraph (DDT), 14 September, 2020



Man and machine are a dangerous duo

By our editorial staff

Following the crash on the A2 highway last week, when two *highway pilot* cars caused a chain collision, questions have been raised about permitting *highway pilot* cars to drive on our highways. And this was not the first such incident. For years the claim was that these cars were perfectly safe, but in light of a recent spate of accidents, is that position still tenable? We spoke with Hans de Maagd, professor of Applied Human Sciences and head of the Humans & Machines department at the University of Groningen.

What exactly is the highway pilot-function?

"The highway pilot function is a new gadget in some cars in the luxury segment. There are currently tens of thousands of these cars driving around in the Netherlands. The attraction of the highway pilot is that he takes over all the driving tasks when you are on the highway; for example, one brand's advertising slogan is, 'Take a break, take a car'. When merging onto the highway, you tell the car what exit you want and then the rest happens autonomously: shifting, maintaining speed, changing lanes... The manufacturers say that all you need to do is keep your eyes on the road and pay attention. If something unexpected occurs – like sudden heavy congestion during rush hour or a road accident – you can immediately take over the driving tasks."

That's sounds great, a car that steers itself. What went wrong?

"My department is of course following developments very closely, and as we've seen in the past, the human has once again proven to be the weakest link. It sounds so simple: keep your attention focused on the road. But many people cannot sustain this and look for some kind of distraction. And that was clearly the case last week. The two drivers involved were busy doing other things. I believe one was changing a USB stick and the other talking on the phone. And that's perfectly understandable: human nature is to always want to be doing something. But of course it's tragic, that this resulted in dead and injured."

You also conducted practical tests with the highway pilot. What were the results?

"Yes, that's right, last year some students from our faculty conducted a simulation with the *highway pilot* lasting several days. They sat in a test setup that simulated realistic road situations; they were therefore required to always keep their eyes on the road and pay attention, and sometimes they had to take the wheel. Just like in real life. They wore measuring devices on their heads to record their eye movements. And what happened? Once the novelty had worn off, which happened after just a few minutes, most of them grew bored: their eyes began to wander in all directions, some even fell asleep, or they began looking at their phones or playing with an app. The students later reported that they were extremely bored. They found the requirement of keeping their hands on the wheel and eyes on the road to be more difficult than actually driving a car."

"And that's also how it goes in real life. There will often be that irresistible temptation to just quickly send an email or put on some makeup or shave... Why else do you have the *highway pilot-function*? The drivers who caused that accident last week were not really reckless per se. My belief is that the highway pilot was developed with an overly optimistic view of mankind in mind. Not enough fundamental knowledge about human behavior was incorporated in the design. Do nothing yet remain alert... that's proven to be an impossible combination."

Do you believe the *highway pilot* should be banned?

"As an independent scientist, I will not comment on this. I know well that the government is busy preparing a campaign to once again explain the benefits of the *highway pilot* and convey to car drivers that they must pay attention at all times. Of course, the politicians in The Hague have high expectations for these systems. There'd be less congestion, fewer accidents, and subsidies have been granted to make these cars as attractive as possible. The Netherlands is a world leader in these cars... However, I'd seriously advise against launching such a campaign right now. You can already see the discussions emerging in the media. On the website NoLevel.nl, drivers with *highway pilots* are called a 'menace on the road'. "Last week the number of secondhand *highway pilot*-cars for sale rapidly increased. People want to get rid of them. It will be difficult to reverse this negative trend."

"However, the main objection I have is this: a publicity campaign does not change the fundamental fact that, in this case, man and machine are a dangerous duo. I think it's better to count one's losses at this point. And this also applies to the carmakers: for now, they should solely focus on the simpler systems, like automated parking – now that's something that we here at Applied Human Sciences can say is a great idea!"

Conclusion and policy action points

Key drivers

On the transition path to a future self-driving vehicle transport system, an intermediate stage is likely, when the technology takes over certain driving tasks but the person must remain actively alert. How this-Consequentlystage unfolds will have a major impact on determining what the future holds.

Who	What
Consumers	Trust in safety of level 1-2
Industry	Profitability of level 1-2 systems
	Technological possibilites
Government	(Perceived) positive effects of cooperative vehicles on traffic flows, safety and the environment (outside of cities)

Table *Summary of key drivers for consumers, industry and government*

If the cooperation between man and machines is not going well, because for instance the driver's attention wanders when monitoring the driving tasks, dangerous situations will arise, thereby undermining support for self-driving technology and the technology's sales and profitability. However, should the experience prove positive, the trend – following a few years of successful 'man-machine' – will likely be towards developing more advanced and more automated self-driving vehicles. Similarly, if man and machine work well together and everyone is satisfied, some delay in further developing more advanced self-driving vehicles is also likely.

Policy action points

With an eye towards action points for policy, we distinguish between the following: regulation and coordination; facilitation and execution; conducting research; and monitoring and evaluation. The key policy action points during the transition are listed in a table on the back cover.

Regulation, coordination and conducting research
Simulator experiments and practical pilot projects are used in this stage to provide insights into the question whether humans and machines can optimally support one another – otherwise known as the human-machine interface – and if so, how? Such insights could lead to changes in driving license and driving lesson requirements. Driving lessons, for example, could now focus more on the interaction between humans and technology. The partially automated systems that directly impact traffic safety could also periodically require comprehensive inspections.

Facilitation and execution
Facilitation and execution could focus on the placement of road lines and signs (see also Morsink *et al.*, 2016). To autonomously navigate within lanes and safely overtake, base systems, such as *lane keeping*, will function according to these lines, which, crucially, must be clearly visible at all times, including in rain and fog conditions. Additionally, uniformity is key, especially on secondary network roads, as not all roads will have shoulders or dividing lines.

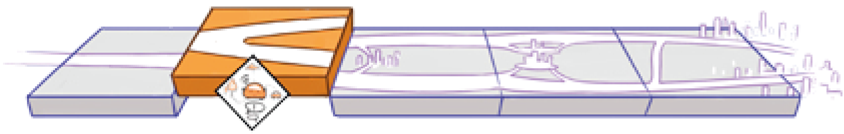
The future is uncertain, and more adaptive planning can help properly contend with this fact. One such approach is to postpone decisions until more certainty exists, while another would be to make *no regret* choices: issues that the government can address in the short-term without regret (see Chapter 8). Additionally, flexible contracts and concessions could provide opportunities for contending with uncertainty and responding to future innovations.

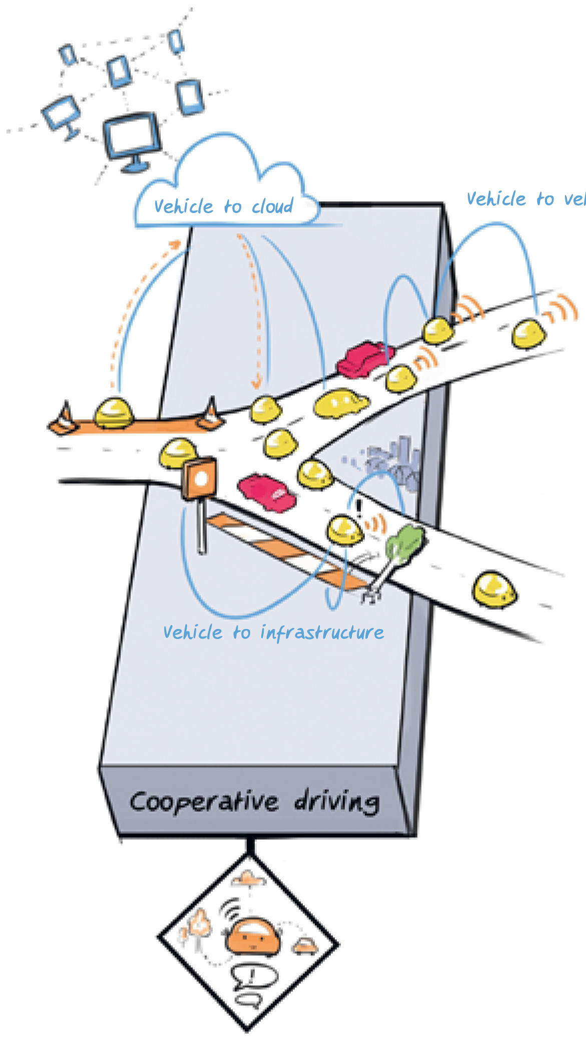
Monitoring and evaluation
Monitoring and evaluation provide important additional insights into the sales and market penetration of automated systems, as well as insights into people's opinions of these systems and their impact on traffic safety, traffic flow and the environment. This fits with the image of adaptive policies: focus on contending with uncertainty and avoiding surprises.

Further transition to higher levels of automation
Pilot projects (level 3-4 automation and cooperative driving) can accelerate the transition to higher levels of automation. This will not only involve facilitating technological development, but also ensuring that the transition proceeds as smoothly and safely as possible. To allow drivers to relinquish control of steering wheels, the Vienna Convention must be amended. Concurrently, agreements must be reached pertaining to the liability and insurability of road accidents.

In addition to experimentation, this stage will also feature discussions about policy goals. Traffic safety, traffic flow (especially cooperative) and emissions (due to safely driving closer together) benefit when humans and machines bolster each other's innate qualities. But what, then, is the added value for governments if they facilitate or even promote the continuing development of fully self-driving vehicles? This could prompt a reconsideration, whereby effective use of time (because drivers no longer need to remain alert) and the social inclusion (of senior citizens, children, the disabled) afforded by automated door-to-door transport, are exalted as key self-driving vehicle (policy) goals.

	Man and machine
REGULATION & COORDINATION	Amendment to Vienna Convention Authorisation of level 1-2 vehicles Liability and insurability Driver's license requirements Human-machine interface
FACILITATION, EXECUTION, & EXPERIMENTATION	Road lines and signs in order Adaptive planning and contracts (innovations) Cooperative and level 3-4 pilot projects
CONDUCTING RESEARCH	Human-machine interface Criteria for driver's licenses Safe cooperative systems Consumers' attitudes toward cooperative driving Required digital infrastructure (V2I, V2C)
MONITORING & EVALUATION	Development of sharing: to 'Sharing in bloom'? Sales and penetration of level 1-2-systems People's attitudes and acceptance (level 1-2) Societal effects of level 1-2 outside of cities Effects of pilot projects (level 3-4)

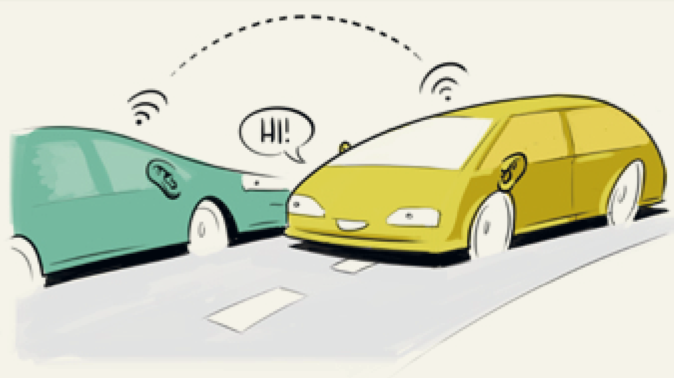



Vehicle to cloud
Vehicle to vehicle
Vehicle to infrastructure
Cooperative driving

4
Cooperative driving: holy grail or bridge too far?

In cooperative driving, self-driving cars communicate with each other and the infrastructure. The vehicles therefore instantaneously understand what the other vehicles will do (accelerate, brake, change lanes), and what is occurring elsewhere on the road. This technology allows vehicles to drive closer together, and the traffic to flow more evenly, resulting in less congestion and increased road safety. *Reliable communication and data exchange* is a key prerequisite, however, as otherwise unsafe situations could arise, including from system hacks. Privacy concerns also play a role where data is concerned. In this chapter we describe two scenarios: one in which cooperative driving has beneficial societal effects ('the holy grail'), and the other in which safe cooperative driving is simply a bridge too far.

The New Digital Telegraph (NDT), 17 January, 2032



Cars that see and hear everything

By Rien Harms

In 2031, traffic congestion once again fell by 8 percent, according to the KiM Netherlands Institute for Transport Policy Analysis' report, *Cooperative (through) driving*, published today. The institute concluded that this long downward trend also continued last year, thanks to an increase in cooperative driving. Self-driving cars continue to get better at communicating with each other, and consequently traffic congestion continues to steadily decline. The cars drive closer together and the traffic flows evenly. Moreover, these cars rapidly react to accidents and other incidents on the road. Why is this development progressing so quickly? And what does future hold?

Cars that understand each other

Fatima El Amrani, KiM's executive director, explains: "Vehicles now flawlessly share information about what is happening on the roadways, and this really is a revolutionary development. Cars and trucks not only talk with each other, they also understand each other, and this is part of what is already a longer-term development. In the past, when we wanted to convey information, we called each other. That was one-to-one communication. Then we started using WhatsApp and could share information within a wider social circle, which was certainly an improvement, but it was still contact between people. Then, things also started talking to each other, the breakthrough that was known as the 'the internet of things'. Consequently, it was a logical step for cars to start communicating; they now know exactly what the other traffic is doing and process that information very quickly. This means that cars can now drive much closer together and there are far fewer accidents. It's no wonder that year after year we see reductions in traffic congestion."

A decisive Europe

Cooperative driving owes much to Europe. European Union member states are notorious for agreeing on very little, but when it became clear that communicating cars would have a positive impact on traffic congestion, road safety and the environment, they all agreed that this was an opportunity that no one wanted to miss. Agreements were very quickly reached and enshrined in the *Declaration of Amsterdam*.

Jan Kees van Gelder, a EU policy officer closely involved in drafting the agreement, fondly recalls the events: “The member states were surprisingly quick to align. After closely consulting with industry, we were able to reach agreements on EU-level system standards within six months. The privacy aspect was slightly more sensitive, because who was really now the owner of all that data and who had access to all that information? However, by instituting strict regulations, we were able to resolve this issue to everyone’s satisfaction.”

On speaking terms

After the signing of the Amsterdam declaration, developments progressed quickly. In collaboration with industry, all the member states provided the necessary roadside and IT systems. Ronald van Swieten, director of Cooperative Technology, represented the Dutch ICT developers during the negotiations in Brussels and Amsterdam.

He also has fond memories: “All of us can certainly still remember our initial experiments with cooperative trucks. In the beginning everyone thought it looked so strange, these truck-trains travelling across Europe, initially in separate lanes but later mixing with the regular traffic. Matters proceeded surprisingly well and were quickly followed by a gradual upscaling. My office made an important contribution to further developing and protecting the systems. And of course it doesn’t stop with trucks. Most drivers recognised the benefits of cooperative driving, and in no time the majority of new cars were *on speaking terms*. I’m proud that we – as a small Dutch company – knew how to facilitate this development. The technology has proven to be reliable, and cyber-hacks have failed to materialise.”

The technology does not stand still

Less congestion, fewer accidents and a cleaner environment: cooperative driving is a story with a happy ending. Or is this story still unfolding? KiM’s El Amrani thinks so: “Another chapter will be added. Not all cars are currently equipped with cooperative technology, but that will definitely happen. The technology does not stand still. As the systems continue to improve, cars will not only be able to communicate with each other on the highways, but also in cities, and it is precisely the most congested cities that will benefit from cars that see and hear everything. It’s only a matter of time.”

Business News Digital, 3 March, 2029

Cooperative driving temporarily halted

Carmaker Xyzo also pulled the plug following last week's hack

3 March, 2029. By our reporter, Jack Werveling

The hack that caused major chaos on the roads around The Hague region last Tuesday seemingly spells the end for cooperative driving. Japanese carmaker, Xyzo, announced today that it was withdrawing from a consortium that promotes cooperative driving in the Netherlands. Speaking at the press conference, the company's CEO, Ger Manco, admitted that he had long-held doubts about the future viability of cooperative driving. The latest hack however was the straw that broke the camel's back. Manco: "We cannot guarantee the safety of cooperative driving. We have apologized to all users." Consumer organisation, Copo, stated back in 2023 that the systems could be hacked, which Manco dismissed at the time as "total nonsense".

Dismantling

With the South Korean company, Kimco, also withdrawing earlier this week, the dismantling of the consortium seems to be a reality. The Dutch Ministry of Infrastructure and the Environment is also considering whether to cancel the subsidy scheme for cooperative driving. "With a heavy heart," a ministry spokesman said. "The benefits that cooperative driving has for decreasing traffic congestions are therefore also over."

'Privacy for all'

Last week's highly organised hack was the work of hacker collective, Privacy for All. Following the hack, the computer fanatics assumed total control over all vehicles. Dozens of cars equipped with cooperative driving systems braked at exactly 5 o'clock, stopping sideways on the highways, with their drivers having no control at all over the maneuver. It was a miracle that no one was seriously injured, although many cars were damaged. Towing companies worked through the night to tow away all the hacked vehicles.

Rijkswaterstaat's crisis center also worked overtime to get traffic in the Randstad flowing again. It was also announced yesterday that the hackers had also deleted all data stored on the central computer in Rijswijk. The police and other law enforcement agencies are now frantically trying to identify the perpetrators. The hacker group posted a message online stating that their aim was to wake people up: “Our action may seem dangerous, but we deliberately waited until the traffic was already slowed by congestion. What in fact is risky is that the government knows exactly where you are at all times!”

Series of problems

This hack was not the first setback for cooperative driving in the Netherlands. Soon after the first cooperative driving cars took to our roads in March 2023, serious technological problems came to light, including that their sensors did not always function properly in rain and fog conditions, resulting in multiple rear-end collisions. These ‘teething troubles’ were largely resolved, but many drivers were no longer enthusiastic about the new system.

Despite a generous governmental subsidy scheme, the number of vehicles with on-board cooperative driving systems has increased very slowly. Moreover, some insurance companies chose to err on the side of caution, refusing to offer car insurance to cooperative vehicles. The national privacy watchdog recently launched an investigation into the potential privacy issues of sharing information with other vehicles and external cloud systems.

Lack of trust

Another persistent problem was the lack of coordination between the systems offered by the various carmakers. For years the EU has been trying in vain to develop a single European standard for cooperative driving systems. However, the attempts have failed due to a lack of trust: most carmakers refused to share their technological data with their competitors. Consequently, the vehicles of the various carmakers do not communicate well with each other. Creating the consortium was a first step towards more concerted efforts between manufacturers.

More congestion

A ministry spokesman said they expect that automakers will now tentatively focus only on autonomous driving systems, which is likely bad news for highway traffic flows. “Autonomous systems are indeed enjoyable to use for individual car drivers, but the downside is that they must maintain large following distances from other vehicles. They do not communicate with other vehicles. Instead, they must read all the sensors, lasers and radar systems in the surrounding area, and consequently they have an even slower reaction time than a person driving the car himself.” Autonomous cars maintain particularly large distances in heavily congested traffic situations, the spokesman remarked: “If more autonomous systems eventually come onto our roads, traffic congestion could even worsen.”

Conclusion and policy action points

Key drivers

Cooperative driving – whereby vehicles communicate with one another and the infrastructure – is a counterpart to fully autonomous driving, in which the vehicles do not or barely communicate with one another, but this is not dependent on a certain level of automation. In principle, level 1-5 vehicles could be both cooperative and autonomous. A key distinction is that for cooperative driving, a crucial prerequisite is the ability to safely drive closer together and thus facilitate certain societal benefits, including improved traffic flows and environmental efficiency. Shared communication allows vehicles to instantaneously understand what vehicles further ahead in the traffic flow are doing and react accordingly.

Cooperative driving does have a potential downside: the looming dangers associated with all this shared communication and data exchange, including cyber hacks capable of disrupting the traffic system. Difficult questions about data ownership and privacy persist: who owns and has access to the data and how transparent is this? If people lack confidence in the system's security, this could undermine public support for cooperative driving, which in turn will negatively impact the sales and profitability of such technologies. Moreover, less cooperative technology could result in fewer benefits for traffic flow, the environment and possibly safety. Rendering cooperative technology safe and robust is therefore a persistent challenge. Additionally, (international) coordination and standardisation is needed to ensure that, crucially, all various makes and models can communicate with each other, also outside of their own national borders.

Who	What
Consumers	Trust in protection against cyber-hacks
	Trust in privacy protections
Industry	Profitability of cooperative systems
	Safety and robustness of cooperative technology
	Possibilities for international standardisaton and coordination
Government	(Perceived) positive effects of cooperative vehicles on traffic flows, safety and the environment

Table *Summary of key drivers for consumers, industry and government*

Policy action points

With an eye towards action points for policy, we distinguish between the following: regulation and coordination; facilitation and execution; conducting research; and monitoring and evaluation. The key policy action points during the transition are listed in a table on the back cover.

Regulation and coordination

The government plays a key role in further developing cooperative driving. Hence, in principle, governments could make a principled choice to support cooperative driving and demand that industry achieve certain levels of standardisation. The US government recently expressed its intention to soon require that all new vehicles be capable to communicating with each other (*vehicle-to-vehicle*, NHTSA, 2016). Moreover, the careful consideration of issues pertaining to privacy and the ownership, use and storage of data remain crucial at this stage.

Facilitation, execution and conducting research

The government must decide which digital infrastructure to invest in at this stage. This can pertain to physical roadside systems, or, conversely, are mobile networks now so far developed that information can be exchanged easily and quickly via clouds? Here, too, regulations must come into play, ensuring that network capacity is always and everywhere available, so that cooperative driving is as safe as possible.

Many uncertainties persist regarding the safety of cooperative systems. To what extent can we prevent cyber hacks and their harmful effects? What systems are required for cooperative driving? Do we need backup systems in case a system fails (‘*redundancy*’)? Comprehensively testing system security, also in practice, can reduce uncertainties. Moreover, crucially, research should be conducted to gain good insights into the support that exists among the public and possible changes therein.

Monitoring and evaluation
Monitoring and evaluation provide additional key insights, including about cooperative systems’ sales and market penetration and associated societal impacts. Here, also, the public’s attitude toward and acceptance of cooperative driving should be monitored, including for any changes therein.

Further transition to higher levels of automation
Various policy action points pertain to the proper channeling of a future involving level 3-4 vehicles, and although these action points are not specifically related to cooperative driving, they must nevertheless be considered in an early stage of the transition. These action points can also play some role in the ‘Man and Machine’ (Chapter 3) stage, especially because they partly overlap with the ‘Cooperative driving’ stage.

Potentially successful pilot projects involving level 3-4 vehicles are further upscaled during this stage. Additionally, tests conducted to determine the vehicles’ safety levels when driving in mixed traffic also play a key role. Research provides additional insights into the safety and acceptance of following distances during a transition stage when both automated and traditional vehicles drive in the same traffic streams. Research moreover can determine the extent to which lane widths must be altered, given that automated steering is more precise.

Cooperative driving

- Data & privacy
- Authorisation of cooperative vehicles
- International coordination of cooperative driving

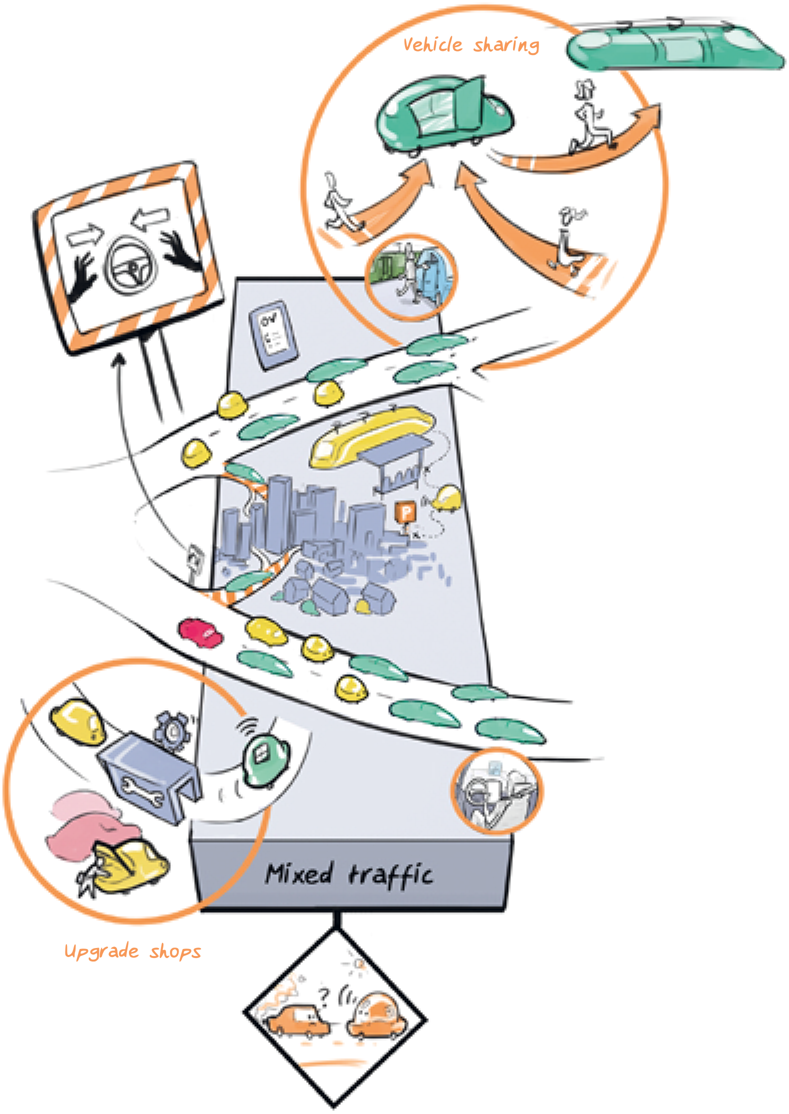
- Investment in V2I, V2C
- Upscaling level 3-4 pilot projects on highways
- Safety tests in mixed traffic

- Ethical issues for self-driving vehicles
- Safe following distances in mixed traffic
- Required lane widths
- Level 3-4: comfort and car sickness

- Sales and penetration of level 1-2-(cooperative) systems
- People’s attitudes and acceptance (cooperative driving)
- Speed of level 3-4 technology development
- Effects of upscaling pilot projects (level 3-4)

Meanwhile, the public may also debate the ethical issues associated with self-driving vehicles, including the choices these vehicles must make when accidents are unavoidable.

Monitoring and evaluation are focused on practical pilot projects, as well as on maintaining the rate of technological development. How fast are level 3-4 vehicles coming onto the market? And how are GPS-, sensor-, camera-, radar- and laser-technologies developing? Developmental breakthroughs could for example allow vehicles to drive closely together without having to use cooperative technology. Moreover, breakthroughs could occur in the field of cooperativity (*'swarm technology'*, for example), whereby vehicles could react to one another much more quickly and efficiently in traffic situations.


Vehicle sharing
OV
Mixed traffic
Upgrade shops

5
Mixed traffic on the highway: solvable or showstopper?

Depending on the technological progress and public levels of acceptance, increasingly more sophisticated automated vehicles will be driving on our roads during the transition to a future involving self-driving vehicles. Concurrently, older vehicles will slowly disappear from our roads, meaning that for a period of several decades these ‘dumber’ and smarter vehicles will drive together on the same roads. This stage, marked by the *interaction between vehicles*, is pivotal. In this chapter we describe two scenarios: in one, ‘solvable’, the self-driving vehicles largely share the road without incident, while in the other, the ‘showstopper’, the transition proves more problematic.

Automated driving: drivers are very satisfied

5

QUESTIONS

… about automated driving

The Hague, 26 May, 2033

By our reporter, Nienke van Gelder

Car drivers are generally extremely satisfied with automated driving on highways, according to a survey published this week by the TNS-NIPO trade association, on behalf of BOVAG RAI. The situation has rapidly progressed since 2015. What are the benefits of automated driving, and will we soon all be driving in self-driving vehicles?

HOW HAS AUTOMATED DRIVING DEVELOPED?

The first passenger car models were the Tesla Model A and the Mercedes S-Class, launched in 2015. These cars autonomously maintained following distances with other traffic. The level of automation was 1 and 2 (see box), which was deemed quite advanced at the time. Owing to their high purchase prices, however, these cars were mainly popular with high-income earners who liked being perceived as *early adopters*.

Tesla and Mercedes used the experiences of these initial users to get new and improved models quickly onto the market. Passenger cars that could drive fully independently on the highway (automation levels 3 and 4) were available for the first time in the early 2020s; however, these cars required human control when driving in cities.

Level	Description	Example
Human driver monitors the driving environment		
0	No automation	Lane departure warning
1	Driver-supported, but the driver must pay attention to situation on the road	Adaptive cruise control, lane keeping assistant
2	Partial automation	Parking assistant, auto-pilot
The automated system monitors the driving environment		
3	Conditional automation	Autonomous highway driver
4	High automation. In certain locations (parking garage, highway) drivers are no longer needed	Autonomous highway driver, parking garage-pilot, driverless pod
5	Fully automated. No driver needed.	Robot taxi

HOW MANY SELF-DRIVING VEHICLES ARE THERE?

Nearly one in five passenger cars have level 3 or 4 automation, but the majority of passenger cars still have the 'traditional' steering. Converting existing models into cars with higher levels of automation is theoretically possible, but practically never occurs, because software, sensors and lasers must be installed, which is expensive. Automated vehicles are therefore almost always new. So-called driverless pods travelling on fixed trajectories are also operational in some cities and outlying areas; they have partially replaced the traditional manned public transportation, but also complement it in some locations.

Automated driving is now common practice in freight transport. As of late last year, some 60 percent of trucks had automation levels of 3 or 4. Automated driving is advantageous: drivers can spend their working hours either behind the wheel or resting when the truck drives automatically. Consequently, in the freight transport sector, the technology quickly pays off. Large logistics companies were especially quick to adopt this technology.

ALL OF THESE SAFETY LEVELS MIXED TOGETHER ON THE HIGHWAY, ISN'T THAT UNSAFE?

Experts had previously warned that unsafe situations would arise from mixing vehicles of varying safety levels, but thus far that fear is seemingly unfounded. All levels of self-driving cars operate safely and reliably on highways. The BOVAG-RAI survey found that drivers had positive opinions of automated driving. Moreover, drivers of traditional cars found the driving behavior of self-driving cars to be even safer and more courteous than that of traditional car drivers. Approximately 70 percent of those surveyed said it was highly likely that their next car would be a self-driving car (if affordable).

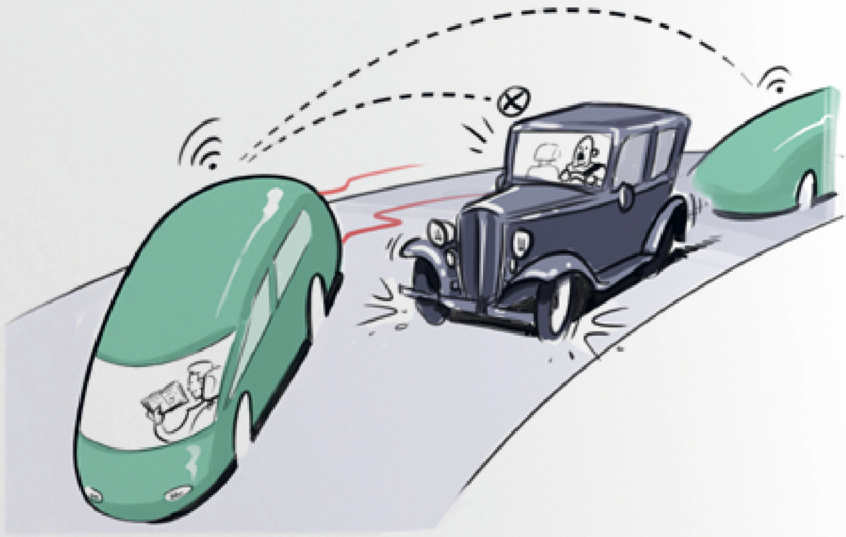
WHAT ARE THE SOCIETAL BENEFITS OF AUTOMATED DRIVING?

Automated driving positively impacts highway traffic flows and the environment, according to the 2032 national traffic monitor. Braking and accelerating produce higher emissions, and automated vehicles do less of this than traditional cars. The impact on traffic safety is also seemingly positive: self-driving vehicles have been involved in very few accidents. The significance of this impact remains difficult to assess however, as the number of traffic incidents on highways was already low.

WHAT ARE THE FUTURE EXPECTATIONS?

Self-driving cars are becoming less expensive to purchase. The more sales, the greater the economies of scale for mass production. The expectation is that automated vehicles will account for approximately half of the car fleet in ten years' time. Highway traffic flows will therefore continue to improve. Traffic engineers believe there is a good chance that automated driving will lead to increased car mobility: self-driving cars drivers are expected to travel more frequently and greater distances than with traditional cars. For working people, residing further away from one's workplace becomes more attractive, for example.

Robot cars creak to a halt. What happened?



The Hague, 26 May, 2031
By our reporter, Ahmed de Boer

5
QUESTIONS
—
... about the demise of the self-driving car

Car drivers are dissatisfied with fully automated driving on highways, according to a survey published this week by the TNS-NIPO trade association, on behalf of BOVAG RAI. All seemed to be going so well for self-driving cars. The robot car would improve traffic safety, while also allowing for more cars on the road per lane kilometer and more efficient uses of our valuable time. But things have turned out differently. The robot car that burst out of the starting gate has come squeaking and creaking to a halt. Consumers have shied away, the government is wary, and the automotive industry is waiting to see which way the wind finally blows. So what happened?

WHAT WERE THE EXPECTATIONS FOR SELF-DRIVING CARS?

Expectations were very high, especially from 2015 to 2020, for this new technology that would make car driving more enjoyable. Human error belonged to the past, because the technology took over all driving tasks. Road safety would be vastly improved and traffic flows also enhanced. Self-driving cars and trucks would be capable of driving closer together, and consequently more traffic could fit on the road. Furthermore, everyone assumed that employers would be delighted as well, because now their employees could engage in work-related tasks while traveling to and from the office. And no, not just making hands-free phone calls like in the past: now they could make complex calculations, write draft proposals and presentations...all while sitting in their 'driving lease-offices'.

HOW MANY FULLY AUTOMATED VEHICLES ARE THERE?

Virtually every car now has one or more driver assistance systems, such as adaptive cruise control; these are useful tools that do their job in background. But as for the number of vehicles that can drive fully automated on highways, that figure is still very low. Last year only 3 percent of vehicles in the national car fleet were robot cars, according to the BOVAG-RAI survey. The percentage is higher for trucks, but that sector had already been growing for years now. The TNS-NIPO survey found that only 6 percent of people who now drive 'regular' cars would consider buying a self-driving car in the next five years.

WHY AREN'T CONSUMERS INTERESTED?

Technology freaks have long dominated the debate about self-driving cars. A small circle of enthusiasts was obsessed with all technological possibilities. However, the question of whether the average consumer was equally enthused was barely addressed. Then when the first fully self-driving 'highway cars' came onto market – like the Google Fata Morgana and Apple Tabula Rasa – it turned out that consumers simply found manual driving much more enjoyable. The consumer is devoted to his stick-shift and does not want to hand over control to the machine. Added to that, shortly after launch, all manner of seemingly dangerous situations arose, especially when the traffic merged and overtook; of course, this all transpired safely, but still, many people felt their hearts skip a beat when the robot cars would cut right in front of another 'traditional' car. And then on top of this were the costs: the first automated vehicles were reserved for the affluent happy few, which resulted in people looking askance and speaking scornfully about the 'money pods'.

WHY DIDN'T THE GOVERNMENT INTERVENE?

The government – especially the Janssen II cabinet – was initially positive, encouraging and facilitating the development of automated driving. However, following fierce and negative debates in the (social) media, the government grew cautious. The opposition party, *Forward Netherlands*, demanded that consumers not be forced to accept it. And then when a referendum was tabled last year about the desirability of self-driving vehicles, the government grew wary. Regulations pertaining to robot cars were provisionally retracted. Moreover, separating traffic – such as separate lanes for self-driving trucks – is now off the agenda, for the simple reason that it's deemed to be too expensive.

WHY DID THE AUTOMOTIVE INDUSTRY ALLOW IT TO FAIL?

The auto industry of course closely followed how the first self-driving vehicles were received. It quickly became apparent that consumers were not overly impressed, and that employers had no intention of investing in these expensive driving robot-offices – also because working in these cars proved unproductive. And the sales were disappointing, which was yet another reason why the momentum petered out. For a robot car to function properly, a lot is involved. Developing a secure system that is also a good match for the human psyche is difficult. The automotive industry did try to make self-driving cars 'more human', for example by ensuring they maintained longer following distances and would brake and accelerate less quickly, but this does not satisfy the deeply held desire to have control over the vehicle. Moreover, the longer following distances proved a detriment to traffic flows, which the government was not happy about, either.

Conclusion and policy action points

Key drivers

As technological developments render level 3-4 feasible, a stage emerges in which these vehicles will mix with non-automated vehicles. The extent to which this occurs will largely depend on how safe and robust industry can make self-driving vehicles. At issue here is both the safety of the vehicle when driving in all weather conditions, and how well and predictably the cars can interact with other vehicles. Drivers of non-autonomous vehicles must not feel frightened or uncomfortable when driving and merging with self-driving vehicles. Sudden sharp turns can create dangerous situations, which could further erode public confidence in self-driving vehicles and adversely affect the sales and profitability of self-driving technologies, and that in turn could subsequently impede the technologies' further improvement and development.

Large following distances could serve to build confidence in self-driving technology among drivers of traditional vehicles; however, larger distances could also diminish the positive impact that self-driving (cooperative) vehicles have on traffic flows. Large following distances could even worsen traffic flows, at least temporarily, which would undermine public and governmental support.

In addition to confidence in safety, additional key drivers are how people experience the convenience and *funfactor*. Market penetration will be a long process if the convenience and added value of self-driving vehicles are not readily apparent, or if people continue attaching great value to what they deem to be the sheer driving pleasure of steering and shifting themselves. If no additional policy discouraging manual driving is forthcoming, a mixed driving scenario could endure for a long period of time, resulting in even less favorable societal effects than currently envisioned (especially pertaining to traffic flows).

Who	What
Consumers	Trust in safety of level 3-4 in mixed traffic
	Experience the convenience and funfactor of level 3-4
Industry	Profitabilty of level 3-4 systems
	Safety and robustness of technology in mixed traffic
Government	(Perceived) positive effects on traffic flows, safety and effective use of time (especially outside of cities)

Table *Summary of the key drivers for consumers, industry and government*

Policy action points

With an eye towards action points for policy, we distinguish between the following: regulation and coordination; facilitation and execution; conducting research; and monitoring and evaluation. The key policy action points during the transition are listed in a table on the back cover.

Regulation and coordination

Chapter 4 concluded by stressing the importance of extensively testing and upscaling pilot projects involving level 3-4 vehicles. The main approach here was to determine if, and how, these vehicles can safely mix with traditional vehicles in traffic streams. Additionally, the pilot projects focused on determining the comfortable following distances and required lane widths, which will be reduced over time if the technology proves capable of steering the vehicles 'more precisely' than humans. Nevertheless, even if this proves to be the case, lane widths cannot be adjusted until all traditional vehicles disappear from the roads, which could take several decades, even if the vast majority of people favor self-driving vehicles.

If the tests are successful, level 3-4 vehicles that can automatically drive on highways will now come onto the market. However, before this can occur, various ethical issues associated with self-driving vehicles must be resolved, including the choices the vehicles must make when accidents are unavoidable. Agreements must also be reached about vehicle authorisation, with international coordination vital in order to prevent situations in which vehicles are suddenly incapable of safely driving automatically once they cross a national border.

Similarly, consideration must be given to the uniformity of self-driving vehicles' driving behaviour. Should there be a minimum (and possibly maximum) permissible following distance? How must they behave when merging on highways? Can this already occur automatically at the start of the transition? And who has priority, automated cars over non-automated cars, or vice versa? Or do vehicles exiting the highway have priority over those entering? Or will this all simply transpire faultlessly? An additional consideration: how much latitude should industry have in giving their vehicles individual characters. Today's car brands have their own images. Some cars are sportier, while others focus more on comfort. To what extent can such characteristics be embodied in self-driving vehicles? Will some self-driving vehicles accelerate more quickly than others? Will they turn differently? And are such differences desirable in terms of traffic safety, traffic flows and the environment? Such discussion points must be resolved at the start of this stage.

Facilitation and execution
If, from the road safety perspective, the experiments prove less successful in mixed traffic, a balance must be struck at this stage between restricting self-driving technology or accepting certain (limited) safety issues, as is now the case (with human drivers). Much will depend on just how (un) safe the technology is and what is deemed to be socially acceptable. Consideration could be given to only allowing self-driving vehicles to drive in separate lanes, thereby increasing safety; however, without additional investments in infrastructure, the traffic flows and capacity on existing roads could suffer as a result.

To invest or not invest in separate 'self-driving lanes' is perhaps a more pressing question for trucks, as trucks are heavier and have longer braking distances, hence, the consequences are greater if anything goes amiss. Transport companies see great profit in the truck-train 'platoons' afforded by self-driving technology. But if, and how, these platoons can operate safely in mixed traffic remains a question. The challenge lies in allowing passenger cars and trucks to merge in and out, yet where the platoon formation occurs also plays a role. How will this occur in heavy traffic situations, as manned vehicles merge in and out and change lanes? If platoons are formed prior to driving on the highway, can these truck-trains subsequently merge safely into a mixed traffic flow?

Because highway traffic lanes are physically separated, highways will serve as the controlled environments where level 3-4 vehicles are initially allowed to drive. The subsequent positive effects can then be further rolled out to major ring roads and other continuous (80 to 100 kilometer) stretches of two- and three-lane roads, although it is questionable whether truck platoons could operate on two-lane roads, especially if there are different speed limits for passenger cars and trucks.

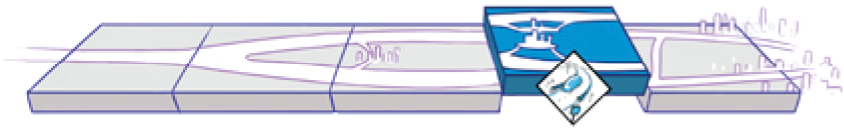
Monitoring and evaluation
As in the other transition stages, monitoring and evaluation play a key role in this stage. The sales and penetration of self-driving vehicles are monitored, as well as public attitudes toward the technology. Additionally, the impact on traffic flows, safety, the environment and infrastructure (damage from the truck platoons, for instance) must be comprehensively measured and evaluated.

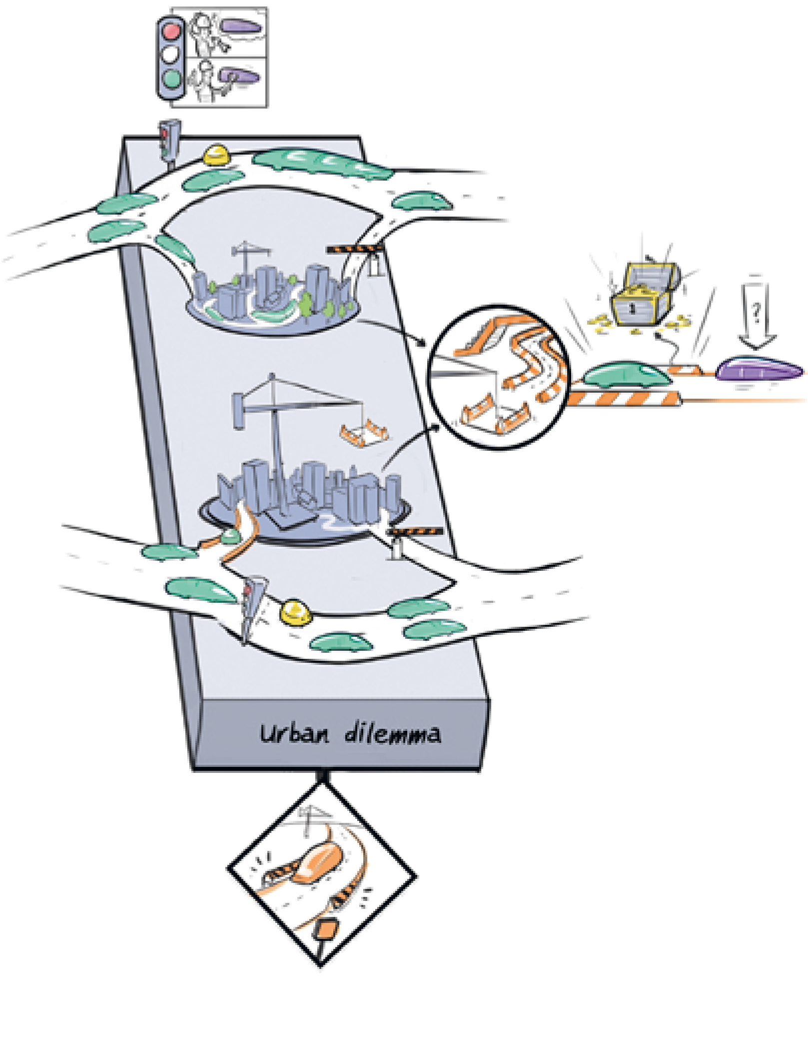
Further transition to higher levels of automation
If the level 3-4 experiences are positive in non-urban areas, yet level 5 vehicles remain a long way off, the government could decide to make certain roads in the city suitable for automated driving. Research would then be conducted to determine

	Mixed traffic
REGULATION & COORDINATION	Ethical issues for self-driving vehicles Authorisation of level 3-4 vehicles International coordination of level 3-4 Minimum following distances Regulations for merging in and out of lanes
FACILITATION, EXECUTION, & EXPERIMENTATION	Yes/no separate lanes for level 3-4 Yes/no adjusting width of lanes Level 5 pilot projects in cities
CONDUCTING RESEARCH	Desire of consumers to autonomously drive in cities Required interventions and costs of level 4 in cities When level 5?
MONITORING & EVALUATION	Sales and penetration of level 3-4 systems People's attitudes and acceptance (level 3-4) Societal effects of level 3-4 in practice Speed of level 5 technology development Effects of pilot projects (level 5)

how important people find such a development, and what infrastructural changes would be required and what they would cost. Such infrastructural changes could include physically separating car and bicycle traffic, and reducing the number of intersections.

In order to avoid any unnecessary investments, the speed of development to level 5 must be closely studied and continuously monitored. If, in this stage, the technology is sufficiently developed, the first pilot projects involving level 5 vehicles could be held in the city.




Urban dilemma

6
Urban dilemma: do nothing or separate traffic streams?

This chapter focuses on the *interaction between car and infrastructure*, with the starting point being that the majority of vehicles on the road are level 3-4. These vehicles drive automatically on highways. Level 5 vehicles are not yet developed, and if and when this fully self-driving technology will arrive remains highly uncertain. Experts have differing opinions about this. Given this uncertainty, an urban dilemma could arise: should investments in expensive (infrastructural) measures be made to allow level 3-4 vehicles to drive automatically on certain city routes, or is it prudent to wait for level 5? We present two scenarios in this chapter: in the first, ‘separating the traffic streams’, a referendum calls for investment, while the second scenario highlights the benefits of ‘doing nothing’.


ON 15 JANUARY, 2045 YOU CAN GO TO THE DIGITAL BALLOT BOX.
THE QUESTION IN THE BURGERDAM CITY REFERENDUM IS:
ARE YOU FOR OR AGAINST THE CITY INVESTING IN THE SEPARATION OF TRAFFIC STREAMS?
VOTE FOR
The Mobile-Burgerdam.nl platform advises you to vote FOR! Mobile-Burgerdam.nl is a coalition of political parties, companies, environmental groups and car aficionados.

Every day car drivers enjoy the benefits of automated driving outside of the city. You can rest while on the highway, spending your time in the car productively. Until that it is we arrive in the city! There the rest and convenience is replaced by congestion, delays and dangerous situations on the road. Together, we will put an end to this by separating car driving, cycling and walking routes from each other! Four reasons why you must vote **FOR**!

1. Improved traffic safety
Thanks to the new technology, the highway has become much safer. The number of traffic fatalities and injuries has dropped by 60 percent since 2020. We can also achieve those safety levels in the city if we separate the main roads for cars, cyclists and pedestrians. When everyone has their own roads and paths, traffic safety will greatly improve.

2. Better traffic flows and a better environment
Traffic congestion on the highway has virtually disappeared, which is a big difference from twenty years ago. Back then, traffic was routinely backed up. But now, hands-freely, we smoothly whizz from A to B, which saves travel time and is much better for the environment, and of course we also want to enjoy this in Burgerdam. Today, we are endlessly stuck waiting for traffic lights, but later we will drive, cycle and walk flowingly through the city.

3. A boost for local employment
Separating the roads will of course cost money. The Mobile Burgerdam platform believes that this is an outstanding way to spend municipal funds. The costs will also deliver benefits. Safety, traffic flow and the environment are not expenses! Human lives are not counted in money. Moreover, these investments will help boost the local economy. Millions of euros will be made available over the next five years.

4. There is no fully self-driving car yet, and one is not coming
Some critics point out that the investments are unnecessary, as the arrival of the fully self-driving car is only a matter of time. This argument belongs to the realm of fiction, however. There is no such self-driving car that takes everyone and everything into account, and there likely never will be. The technology is indeed highly developed, but the situation in the city is simply far more complex than on the highway. The only solution is to separate the traffic.

DON'T BE A ROADBLOCK: VOTE FOR!


ON 15 JANUARY, 2045 YOU CAN GO TO THE DIGITAL BALLOT BOX.
THE QUESTION IN THE BURGERDAM CITY REFERENDUM IS:
ARE YOU FOR OR AGAINST THE CITY INVESTING IN THE SEPARATION OF TRAFFIC STREAMS?
VOTE AGAINST
Stopinvestment.nl advises you to vote AGAINST. Don't waste money on separate traffic!

Enjoyably walking and cycling through the city without obstacles, no waste, more money for green areas and quality of life, and happily driving yourself. As a group of concerned Burgerdam citizens, we offer you four reasons for voting AGAINST on January 15!

1. Investing in separate traffic is a waste of money
Separating traffic flows in our beautiful town is not only expensive, it is also unnecessary. Experts expect that in just a few years' time fully automated driving (level 5) will be commonplace. At that level of automation, separating traffic is no longer necessary. Consequently, investing in separated traffic is not only a waste of money, but it could also put our city at a disadvantage compared to cities that do not have separate traffic ('the law of the handicap of a head start').

2. Separation is hardship
Separating infrastructure creates unwanted barriers in Burgerdam. Cyclists and pedestrians must walk and cycle far out of their way in order to cross roads where fully automated driving is permitted.

3. Better to spend the money on a liveable and green city!
Every penny that the municipality invests in separate traffic routes is money that cannot be spent on other truly useful services, like self-driving public transportation and a more liveable and greener city. The residents of our city have been waiting a long time for the central park to be refurbished.

4. Driving yourself is better
Many car drivers are not eagerly looking forward to automated driving in the city, and national surveys prove this point. Automated driving is already possible on highways and many other roads outside of cities, and that is sufficient. The time saved by automated driving in the city is minimal: cars must brake and accelerate much more frequently than on highways and this is extremely uncomfortable. Passengers often even get car sick when trying to read or work en route.

DON'T WASTE MONEY ON SEPARATE TRAFFIC: VOTE AGAINST!

Conclusion and policy action points

Key drivers
A key driver in this chapter is the confusion surrounding the question of if and when level 5 will be possible. Should such vehicles arrive quickly, investing in separate traffic flows is less useful. However, if it will be a long time before they arrive, investment in infrastructure is indeed a viable option. For the (local) government, a major motivating factor could be the positive impact on traffic flow, safety and the environment that would occur in some parts of cities, although the impact would be less than outside of cities. By separating urban traffic streams, safety in the city would improve, even without automated driving.

A more effective use of travel time could be another reason for investing. Much will depend on what 'society' deems important, and what considerations this will entail. Automated driving (on some routes in the city) could enhance the convenience factor. However, conversely, the money it would cost to achieve this could also be spent on other issues, such as liveability and health care.

Who	What
Consumers	Experience the convenience and funfactor of level 3-4 in the city
Industry	Technological possibilities: unclear when level 5 is possible
Government	(Perceived) positive effects on traffic flow, safety, the environment and effective use of time

Table *Summary of key drivers for consumers, industry and government*

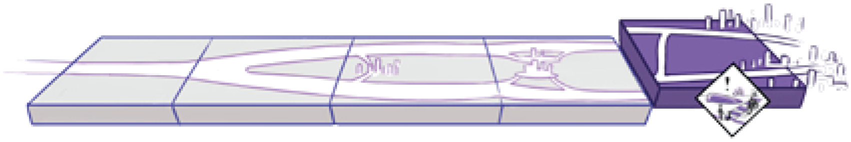
Policy action points
With an eye towards action points for policy, we distinguish between the following: regulation and coordination; facilitation and execution; conducting research; and monitoring and evaluation. The key policy action points during the transition are listed in a table on the back cover.

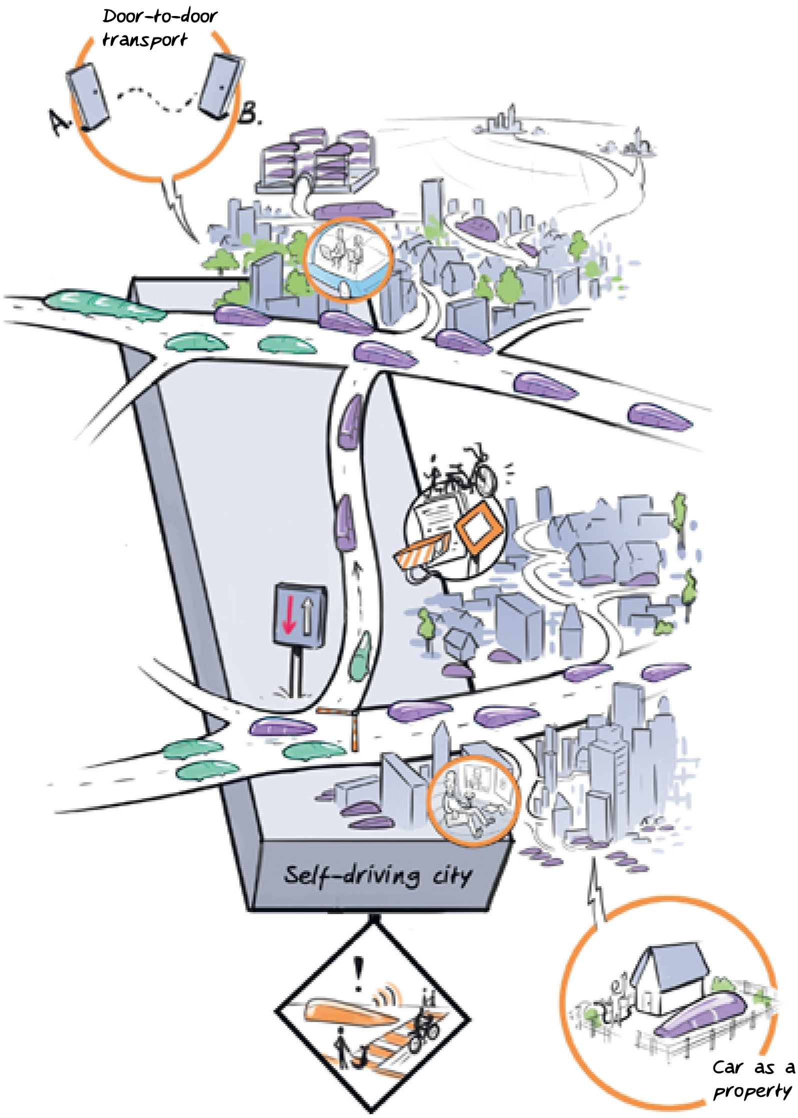
Automated driving in cities is a complex matter, owing to the narrow roads and high degree of interaction with other traffic, including cyclists and pedestrians. In order for level 3-4 vehicles to safely drive on urban routes, any potential conflicts between vehicles and cyclists/pedestrians must be resolved. This could be done by physically separating roads, cycling paths and sidewalks in the city. Additionally, as on highways, road lines and markings should be used to ensure proper position determination (assuming lines are still used to mark positions on roads).

This stage also features certain monitoring aspects; consequently, it is important to monitor how the social acceptance of self-driving vehicles develops in cities, and to measure and evaluate certain societal effects, including urban traffic flows and road safety.

Further transition to higher levels of automation
Unpleasant surprises can be avoided by closely monitoring the technology as it develops in the direction of level 5. When level 5 technology ultimately becomes available, an initial pilot stage will likely follow. If the effects prove positive, the experiment will be further upscaled. In this stage, studying how level 5 vehicles behave in mixed city traffic is an important aspect of the pilot projects, and this could occur on narrow streets and uncontrolled intersections where conflicts with other traffic are likely to arise. Such situations could involve cyclists and pedestrians who stop the 'safe' self-driving cars by haphazardly crossing in front of them, resulting in traffic jams. At this stage, think tanks should consider the question of how self-driving cars can safely and flowingly find their way through cities.

	Urban dilemma
REGULATION & COORDINATION	■ Regulations and guidelines for safe and fluid level 3-4 driving in cities
FACILITATION, EXECUTION, & EXPERIMENTATION	■ Adjusting routes in cities for level 3-4 ■ Road lines and signs in order in cities ■ Upscaling level 5 in cities
CONDUCTING RESEARCH	Measures for level 5 in cities: ■ Physical separation of transport modes ■ Smart cameras and sensors ■ Low speed limits in cities ■ ‘Forceful’ vehicles
MONITORING & EVALUATION	■ People’s attitudes and acceptance (level 3-4 in cities) ■ Societal effects of level 3-4 in cities ■ Speed of level 5 technology development ■ Effects of pilot projects and upscaling (level 5)




Door-to-door transport
A.
B.
Self-driving city
Car as a property

7
Self-driving city: harmonious interaction or contested ground?

We assume that level 5 vehicles are now reality, and drivers have become passengers both in and outside the city. This sounds appealing, but will it actually work in a busy city? In this chapter we explore this *interaction between cars and slow traffic*. In the first of two WhatsApp chats between friends, the self-driving car zooms flowingly through the city, enjoying harmonious interaction with other road users, while in the second chat, matters proceed far less harmoniously, as self-driving cars and bicycles contest for primacy in the limited public domain.

Harmonious interaction

Hi Florien, I’m running a bit late for tennis. I was working so comfortably that I forgot to tell my car to avoid the slower traffic on the side streets. It’s indeed a bit slower, but enjoyable to be in the mixed traffic.

Hi Kees, no problem, I’m also not there yet. I’m on my bike at the light on the Waardersingel, waiting for all the driving mini-offices like yours to pass by...

Ha-ha Florien, and I guess sneaking across isn’t an option? Last time I was on my bike I got a huge fine...

No, this spot’s full of cameras...!

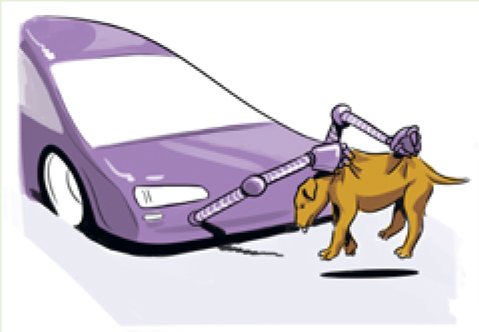
And that’s good, because otherwise you get all those rotten teens crossing for a joke and frustrating everyone. I almost got rid of my self-driving car a few years ago when it was such a mess on the roads. But now it’s well organised.

Yeah, those were bad old days... Just now I cycled along a long stretch of a separate bicycle path. Incredibly relaxing! By the way, what are you up to?

Watching a movie. But what’s even more exciting is that there’s a dog on the loose here...curious how this will end...

...flat as a pancake?

No way, man 🙂. the car just gently pushed him aside.
That little 'hand' on the front works great! 👍



Handy, Kees... I think I'll also get one on my next car.

I can definitely recommend mine, Florien. I've had it for 6 months now and it works great. And not expensive, either.

Yeah, I saw that... prices are really falling fast.

My neighbor's 80 years old and even he just bought a self-driving car. He hadn't driven a car in 20 years, ever since he wrecked his last traditional car. But now it's like he's reborn! Yesterday I saw him and his old buddies playing cards and drinking coffee in his car 🙂🙂.

🙂 Got a green light now...so I'm off...see you soon, Kees!!

Contested ground

Hi Peter, remember how we were recently talking about the self-driving cars in the city? I just read that the robot cars are also now no longer allowed in Rotterdam. Next month you won't be allowed to driver around the city in that cool Tesla of yours.

Hi Kees, yeah, awful ☹☹. I really love autonomous driving. A cup of coffee, surf the net or just rest your eyes for a while and you're there!

Yes, but not in the city.

No, it's a disaster. Awful pedestrians, cyclists... and rotten teenagers.

🤔

...those jerks know that your car will always stop, so they jump in front. They don't have the right of way, but they don't care. And don't get me started on those idiots who throw boxes in the street. Your car always errs on the side of caution.

And that's why I never switched over: dumb computers on wheels.

Yeah, you're better off still steering yourself.

Didn't they say that they'd program it so pedestrians and cyclists would still have to look out?

Yes, Kees, plans and more plans, but nothing happened. All those pathetic, anti-car types 😔.

🤔

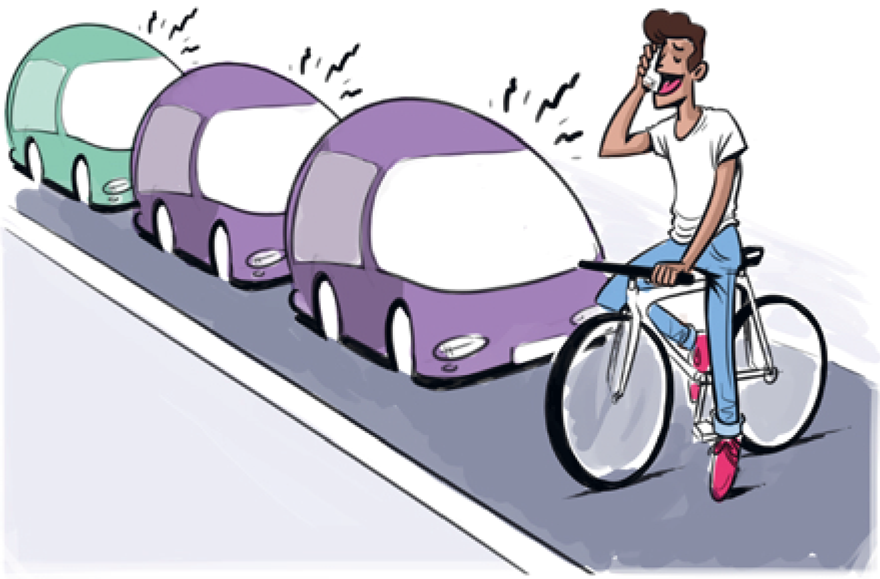
All their whining and sad stories about ‘the liveable city’, ‘domination of the car’ and ‘vulnerable cyclists’. *Vulnerable*... don’t make me laugh! My head almost goes through the windshield, coffee spilt all over the car... and they ride away laughing. 😡. And all the municipalities go along with it! Spineless!

Well, Peter, at least there’s still the highway. 😜

Yes, but it’s still ridiculous that we now have to steer ourselves in the city. 🙁

How does the saying go: an experience richer, an illusion poorer? 😞

An illusion that costs € 65,000 😞😞



Conclusion and policy action points

Key drivers

A key driver in this stage is that level 5 vehicles are now technologically feasible; however, their profitability will depend on the perception of such systems and the consumers' opinions and attitudes. If people find driving automatically in cities unsafe or inconvenient, this could put a brake on market penetration. All the stopping, starting and maneuvering of city driving could mean that doing other things in the car while driving is less comfortable than it is on highways, for example, and some people might even get car sick. If, reactively, from a comfort perspective, the vehicles are programmed to brake and accelerate more gradually when driving in cities, this could prove less beneficial for city traffic flows. Moreover, social support could be eroded if the safety levels of mixed traffic involving cyclists and pedestrians fail to meet the high expectations.

Who	What
Consumers	Trust in safety of level 5 in mixed urban traffic
	Experience the convenience and funfactor in cities
Industry	Level 5 technology possible and profitable
Government	(Perceived) positive effects on traffic flows, safety, the environment, effective use of time, and social inclusion

Table *Summary of key drivers for consumers, industry and government*

Policy action points

With an eye towards action points for policy, we distinguish between the following: regulation and coordination; facilitation and execution; conducting research; and monitoring and evaluation. The key policy action points during the transition are listed in a table on the back cover.

Level 5 vehicles can theoretically do everything themselves, but if and how they will successfully share city roads with cyclists and pedestrians (at intersections and on narrow streets, for example) remains unclear. If reckless, street-crossing cyclists negatively impact traffic flows and safety in the city, this could undermine support for self-driving vehicles.

The challenging question of how self-driving vehicles can safely and flowingly drive in cities was already being considered in earlier transition stages (see also Chapter 6). Tests could be conducted to help answer this question. Moreover, Level 5 vehicles must be authorized during this last stage of the transition, before effectively being upscaled and implemented. Possible measures to prevent cities from becoming 'gridlocked' by mixed traffic involving cyclists and pedestrians include:

- create physical separations between the various transport modes, including roads and bicycle paths;
- deploy smart technology (cameras on cars, sensors on bikes) and regulations to prevent violations;
- low maximum speeds for automated vehicles in certain streets where conflicts are likely to arise (on narrow streets, for example);
- give automated vehicles a 'forceful' character, whereby they will stop for cyclists and pedestrians when necessary, but then 'forcefully' continue driving.

It is uncertain if such measures will be needed. Perhaps the system will regulate itself; for example, cyclists also often use cars, and consequently do not want to be delayed either. Conversely, such measures could prove insufficient when one considers the differing driving cultures that exist between countries and cities, for example. Will it be possible to create a vehicle that can consider all these differences and change or 'ignore' such deep-rooted cultural behaviours? Respectively, good international coordination will be essential to avoid potential problems.

Should level 5 prove feasible, the 'Evolution of the private car' path will continue developing toward the Fully automated private luxury future scenario, when automated vehicles will enjoy high penetration rates. Conversely, level 5 also facilitates inexpensive, shared door-to-door transport, prompting a (partial) shift to the 'Sharing in bloom' path (see also Chapter 2), which in turn could result in a (partial) shift to the world of Mobility as a service: any time, any place. Should this occur, or if the 'Sharing in bloom' path starts earlier than predicted, additional regulations may be needed to ensure fair competition between (large) fleet owners.

If sharing car ownership and car rides becomes commonplace, the social implications for traffic flows, parking and liveability in virtually all transition stages will be profound, especially at the beginning ('Man and machine') and end ('Self-driving city'). It is therefore very important to properly monitor developments, so that prompt reactions to such developments are then possible. Other key issues to be monitored at this stage include the sales and market penetration of level 5 systems, the consumers' wants and needs, and the actual practical effects (on traffic flows, safety, liveability, effective time management, and social inclusion).

	Self-driving city
REGULATION & COORDINATION	■ Authorisation of level 5 vehicles ■ Regulations for safe and fluid level 3-4 driving in cities ■ International coordination (level 5) ■ Regulations for fair competition (for sharing)
FACILITATION, EXECUTION, & EXPERIMENTATION	■ Established regulations for level 5 in cities ■ Required space for parking (if sharing is in full bloom)
CONDUCTING RESEARCH	
MONITORING & EVALUATION	■ Development of sharing: to 'Sharing in bloom'? ■ Sales and penetration of level 5 systems ■ People's attitudes and acceptance (level 5) ■ Societal effects of level 5 (primarily in cities)

8
Conclusions and policy action points

Chapter 2 of this study described two transition paths to a future traffic and transport system involving self-driving vehicles. In the first path – 'Evolution of the private car' – people attach great value to car ownership. In the second path – 'Sharing in bloom' – the sharing of car ownership and trips are completely commonplace. The foundation for these transition paths is the four future scenarios in the KiM report, *Driver at the wheel?* (KiM, 2015a): *Letting go on highways*; *Fully automated private luxury*; *Multimodal and shared automation*; and *Mobility as a service: any time, any place*.

We identified five steps on these paths in which an interplay of developments can profoundly impact the transition. These transition steps are further elaborated in Chapters 3 to 7 and provided with action points for policy makers. In this chapter we summarize the key points and explore what is known as *no regrets* policy. We then discuss the key considerations for deciding to/not to share and to/not to invest in infrastructure.

Policy action points: the five transition steps summarised

This study reveals that the transition to a future involving many self-driving vehicles – whether only driving outside of cities or everywhere – is fraught with uncertainties. If the technological development proves successful, the technology affordable, people embrace self-driving cars and the societal impact is positive, a self-driving future is highly probable. However, possible 'showstoppers' also exist: specific developments that could impede the transition. In this study we identified five steps that can profoundly impact the transition. They are:

1. the interaction between man and machine;
2. cooperative or autonomous driving;
3. mixed traffic;
4. yes/no separation of traffic flows in cities;
5. the 'self-driving city'

These steps are partly successive and partly overlapping over time. Consequently, cooperative driving is partially independent from the development of self-driving vehicles, which are also capable of operating more autonomously (but without inter-vehicle communication). Conversely, a generally held belief is that cooperative driving is needed in order to achieve the more beneficial effect for society.

The speed at which the transition occurs is largely determined by the difference between technological feasibility and the actual penetration in the traffic flow. Even as vehicles come onto the market with certain levels of automation, it still may take several decades before the majority of drivers actually drive in them.

No regrets

The future is uncertain, and the further we look into the future the more uncertain it can seem. In adaptive policy, which contends with uncertainty, the focus is therefore often on *no regrets*: issues that the (national) government can presently pursue without feeling regret later.

Adaptive planning – done to contend with the uncertain developments surrounding self-driving vehicles – is deemed a *no regrets* activity.

The *no regrets* primarily play a role in the short-term, up to the moment that level 3-4 vehicles become available. Many of these *no regrets*, including monitoring and evaluation, are relevant in all transition stages.

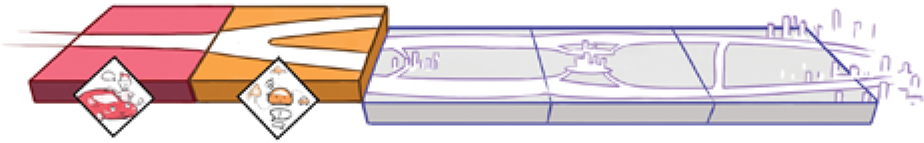
Reader’s guide to table of policy action points during the transition

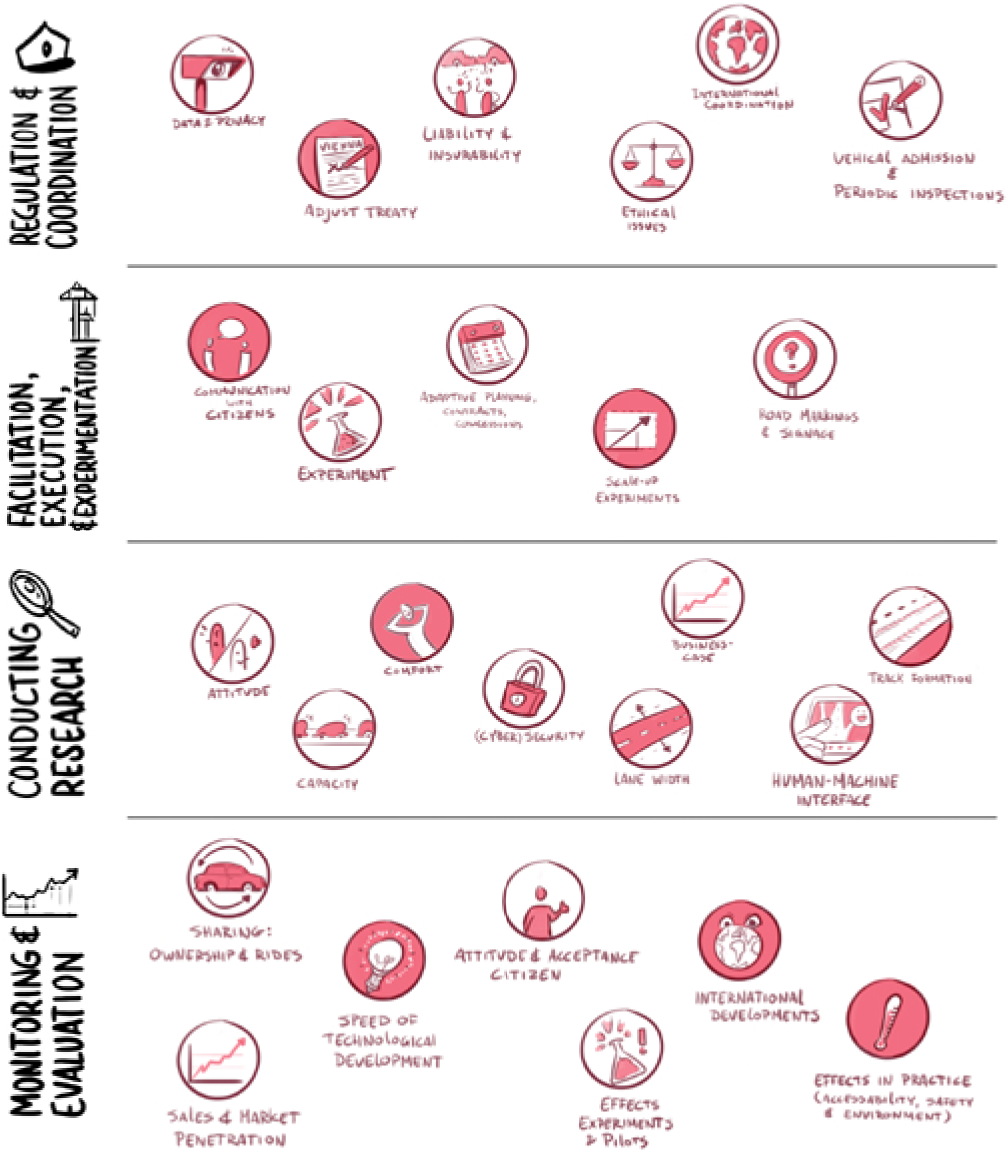
We have identified policy action points for each of the five steps. They are divided into four categories and listed in a table on the back cover:

- regulation and coordination;
- facilitation, execution and experimentation;
- conducting researching;
- monitoring and evaluation.

In the table we denote the policy action points that are specifically related to certain stages in the transition. Additionally, certain policy actions can also help facilitate the further transition process. Consequently, at this stage research could be conducted to determine the functionality and safety of certain systems that will only be rolled out in a later stage, following positive research and test results, for example. Different colours are used in the table to show the links between actions from an earlier stage in the transition to those of a later stage.

Over time, new societal effects can emerge in the higher levels of automation, as is denoted by the transition arrow under the table. The effective use of time emerges starting in automation level 3-4, because people now spend (part of) their travel time on other activities. If level 5 becomes a reality, social inclusion becomes one of the effects: disabled people, senior citizens and children are now more mobile owing to fully automated door-to-door transport




REGULATION & COORDINATION
DATA & PRIVACY
ADJUST TREATY
LIABILITY & INSURABILITY
INTERNATIONAL COORDINATION
ETHICAL ISSUES
VEHICAL ADMISSION & PERIODIC INSPECTIONS
FACILITATION, EXECUTION, & EXPERIMENTATION
COMMUNICATION WITH CITIZENS
EXPERIMENT
ADAPTIVE PLANNING, CONTRACTS, CONCESSIONS
SCALE-UP EXPERIMENTS
ROAD MARKINGS & SIGNAGE
CONDUCTING RESEARCH
ATTITUDE
COMFORT
CAPACITY
(CYBER) SECURITY
BUSINESS-CASE
LANE WIDTH
TRACK FORMATION
HUMAN-MACHINE INTERFACE
MONITORING & EVALUATION
SHARING: OWNERSHIP & RIDES
SPEED OF TECHNOLOGICAL DEVELOPMENT
ATTITUDE & ACCEPTANCE CITIZEN
INTERNATIONAL DEVELOPMENTS
SALES & MARKET PENETRATION
EFFECTS EXPERIMENTS & PILOTS
EFFECTS IN PRACTICE (ACCESSABILITY, SAFETY & ENVIRONMENT)

Sharing as policy choice?

The five transition steps relate to both the 'Evolution of the private car' and 'Sharing in bloom' paths. These two paths primary differ in the degree to which car and ride sharing will increase in society. The 'Evolution of the private car' path also involves shared cars – as is the case today. Over time this path will also feature more automated trains and trams. However, the scale at which this occurs will differ from that in the 'Sharing in bloom' path, where the assumption is that car sharing will rapidly increase in popularity over the coming decades.

The number of car sharers and shared cars is currently marginal and not yet deemed a disruptive development. If the current situation persists, the 'Evolution of the private car' path is more probable than the 'Sharing in bloom' path. However, this could change if future level 5 vehicles render shared door-to-door transport possible and the travel costs per passenger per kilometer are lower than if people own or lease a self-driving car (see BCG, 2016). In that case, it is highly probable that people who primarily drive cars for the convenience they will opt to share cars and car trips. A future of *Mobility as a Service: any time* would then be in the offing.

Whether sharing sees a sharp, short-term increase is seemingly partly independent of how self-driving technology develops. Car sharing fleet administrators or Uber-like online platforms could indeed accelerate self-driving technology's penetration in the traffic flow. Moreover, innovative apps and travel assistants could potentially have a greater short-term impact on the use of (multimodal) sharing systems. Governments could also support or facilitate the development of such systems. Additionally, governments could opt to further improve public transportation. It is however seemingly unlikely that such actions would result in a wholesale switch to shared cars and public transportation in the short term. For this to occur, more is needed, including a change in peoples' attitudes.

Investments in public transport and roads?

If the self-driving (shared) car is coming, should we still invest in new public transport infrastructure? This is an often-asked question and one that is difficult to answer. Public transportation systems are implemented with long time horizons; consequently, if everyone will soon be whizzing around in automated self-driving (shared) cars, heavily investing in new railway connections and other public transport infrastructure is inefficient. However, as level 5 technology is seemingly nowhere in sight, public transportation could benefit from self-driving technology in the short term. Because of the separate infrastructure, it is easier to further automated trains, trams and metros than it is to allow for self-driving cars to drive in mixed traffic. The self-driving shared car seemingly only poses a 'threat' to traditional public transport (buses and trams) when level 5 technology becomes reality. As a no-regrets action, it is perhaps compelling to render public transportation systems as adaptive as possible. Long-term contracts and concessions could over time create space for capitalising on key technological innovations.

The question of whether more or less pavement will be required is seemingly difficult to answer. This will depend on multiple developments: if self-driving vehicles are cooperative, they can drive closer together and hence road capacity will increase without having to widen roads; however, if the vehicles are truly autonomous (not communicating), following distances are unlikely to be shorter, but could even increase if the technology maintains safer following distances than those in our current traffic streams, and, consequently, this could come at the expense of road capacity, thereby creating a need for additional road infrastructure.

Even if the choice is for cooperative technology, it remains uncertain if this will result in capacity gains. In the mixed traffic streams involving cooperative (self-driving) cars and traditional cars (level 0), the initial choice could be for maintaining longer following distances, in order to ensure that traditional vehicle drivers do not feel uncomfortable.

An additional uncertainty concerns the connections between highways and cities. Capacity gains are especially likely on stretches of highway where vehicles can drive close together like trains; however, the chain is only as strong as its weakest link, and it is precisely at the junctions where vehicles enter the city that large capacity gains are difficult to achieve. These are areas where lane-changing maneuvers frequently occur, and hence, provided no level 5 vehicles exist, drivers will have to retake control of the driving. Capacity gains are also more difficult to achieve in cities. How this will all play out on the network level remains unclear, as is whether capacity issues will arise in the transition from highway to city.

In conclusion, by how much demand for mobility will increase when fully self-driving (level 5) is possible, and if this will result in a need for more road infrastructure, is uncertain. Additional demand could be created by groups that currently cannot independently operate cars (the disabled, children), or by car drivers who will travel more because they can effectively use their time spent in cars, or because they use self-driving cars instead of public transportation. Consequently, car traffic volumes will also increase in the *Mobility as a service: any time, any place and Fully automated private luxury* scenarios. However, this does not imply that road networks must also be extended proportionally as a matter of course. In *Mobility as a Service: any time, any place* the market dictates mobility's location- and time-dependent pricing. If demand increases, the price of mobility services increases, thereby keeping demand for mobility and road capacity in balance. This mechanism does not occur in the *Fully automated private luxury* scenario, where private car ownership dominates. However, traffic congestion must be considered very differently in that scenario, because the time spent stuck in traffic can be spent productively.

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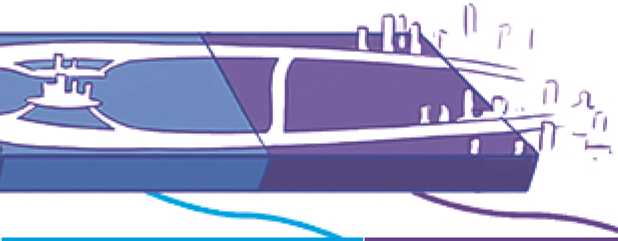
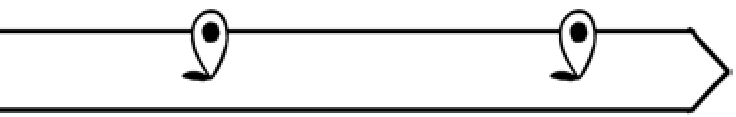
Man and machine	Cooperative driving	Mixed traffic
Amendment to Vienna Convention Authorisation of level 1-2 vehicles Liability and insurability Driver's license requirements Human-machine interface	Data & privacy Authorisation of cooperative vehicles International coordination of cooperative driving	Ethical issues for self-driving vehicles Authorisation of level 3-4 vehicles International coordination of level 3-4 Minimum following distances Regulations for merging in and out of lanes
Road lines and signs in order Adaptive planning and contracts (innovations) Cooperative and level 3-4 pilot projects	Investment in V2I, V2C Upscaling level 3-4 pilot projects on highways Safety tests in mixed traffic	Yes/no separate lanes for level 3-4 Yes/no adjusting width of lanes Level 5 pilot projects in cities
Human-machine interface Criteria for driver's licenses Safe cooperative systems Consumers' attitudes toward cooperative driving Required digital infrastructure (V2I, V2C)	Ethical issues for self-driving vehicles Safe following distances in mixed traffic Required lane widths Level 3-4: comfort and car sickness	Desire of consumers to autonomously drive in cities Required interventions and costs of level 4 in cities When level 5?
Development of sharing: to 'Sharing in bloom'? Sales and penetration of level 1-2-systems People's attitudes and acceptance (level 1-2) Societal effects of level 1-2 outside of cities Effects of pilot projects (level 3-4)	Sales and penetration of level 1-2- (cooperative) systems People's attitudes and acceptance (cooperative driving) Speed of level 3-4 technology development Effects of upscaling pilot projects (level 3-4)	Sales and penetration of level 3-4 systems People's attitudes and acceptance (level 3-4) Societal effects of level 3-4 in practice Speed of level 5 technology development Effects of pilot projects (level 5)



Urban dilemma	Self-driving city	
■ Regulations and guidelines for safe and fluid level 3-4 driving in cities	■ Authorisation of level 5 vehicles ■ Regulations for safe and fluid level 3-4 driving in cities ■ International coordination (level 5) ■ Regulations for fair competition (for sharing)	REGULATION & COORDINATION
■ Adjusting routes in cities for level 3-4 ■ Road lines and signs in order in cities ■ Upscaling level 5 in cities	■ Established regulations for level 5 in cities ■ Required space for parking (if sharing is in full bloom)	FACILITATION, EXECUTION, & EXPERIMENTATION
Measures for level 5 in cities: ■ Physical separation of transport modes ■ Smart cameras and sensors ■ Low speed limits in cities ■ 'Forceful' vehicles		CONDUCTING RESEARCH
■ People's attitudes and acceptance (level 3-4 in cities) ■ Societal effects of level 3-4 in cities ■ Speed of level 5 technology development ■ Effects of pilot projects and upscaling (level 5)	■ Development of sharing: to 'Sharing in bloom'? ■ Sales and penetration of level 5 systems ■ People's attitudes and acceptance (level 5) ■ Societal effects of level 5 (primarily in cities)	MONITORING & EVALUATION



+ Effective use of time (city routes)

+ Effective use of time (everywhere) + social inclusion

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