E-BOOK

Self-driving and cooperative cars

Opportunities for safe, efficient, and sustainable mobility for everyone

Perspectives, need for action and regulation

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The Author

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IKEM Introduction

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The Institute for Climate Protection, Energy and Mobility (IKEM) is an independent, non-profit association and affiliated institute of the Universität Greifswald. The IKEM researches key scientific issues that focus on implementing a sustainable and social order whilst using an interdisciplinary and integrative international perspective. IKEM's central research topics include:

- Expansion of renewable energy sources
- Energy grids that are fit for the future
- Electromobility
- Digitalization, automation, and the networking of transport
- Related traffic and mobility issues
- Implementation of climate protection goals
- Basic issues of energy supply, planning, resource conservation, and efficiency

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Introduction: Science-fiction meets the road

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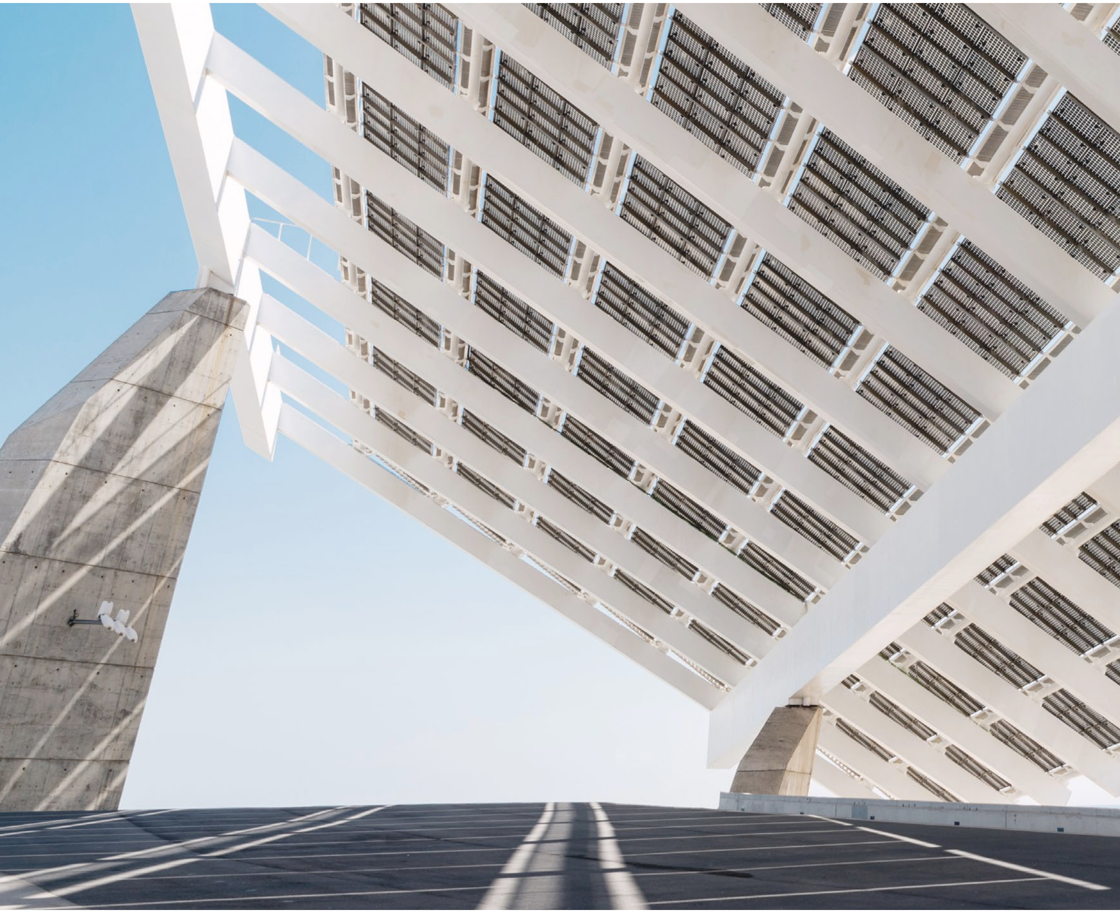

How have self-driving and cooperative cars developed in the past few years?

Do you think of robotic cars as a science-fiction topic? Just a few years ago, many experts would have agreed with you. However, times are changing. In 2004, the US Defense Advanced Research Projects Agency (DARPA) held its first competition in the Mojave Desert. The goal? For participants to develop a car with self-driving modes. The aim was to cover 150 miles within ten hours using a self-driving vehicle control system. The most successful vehicle only managed about 7,3 miles.

Since approximately 2011, several American technology companies have announced that their self-driving vehicles are nearing market maturity. These companies claimed that their vehicles successfully covered hundreds of thousands of test kilometers with only minor interventions from test drivers. Quite an achievement when compared to the short 7.3 miles achieved in the Mojave Desert just seven years prior. But where are the self-driving cars today?

Current situation: Autonomous driving today

Although these announcements may have been considered hasty and exaggerated in retrospect, these companies gave the market an important boost. Cars with self-driving mode (also known as autonomous vehicles, robot cars, driverless, or self-driving motor vehicles) have since made their way to the forefront of mobility research and are respectively hyped up by the media. For a while there was some discussion predicting that robot cars would replace conventional cars and although this may be the case in the future, the excitement has since subsided somewhat and has given way to a more realistic view for today's world.

Today, useful applications are already emerging leading to the self-driving cars being able to handle a fair amount of traffic situations on their own. However, almost all experts agree that long-term human support will be needed in certain traffic situations, as well as in vehicle maintenance and monitoring. In addition, self-driving mode cannot be used in all circumstances.

“Mixed traffic, in which vehicles of different levels of automation, cyclists, and pedestrians participate side by side, will continue to exist.”

Matthias Hartwig

If you think of cars with self-driving mode as science-fiction, you’ll be surprised to find out:

- Where this technology stands today
- Why vehicles with self-driving mode will be soon be used on the road
- Why we can make good use of them (as they can contribute to sustainable, efficient mobility and contribute to road safety)
- What remains to be done on the road in order to achieve sustainable, safe, and efficient mobility for vehicles with self-driving mode.

Background: What are vehicles with self-driving mode?

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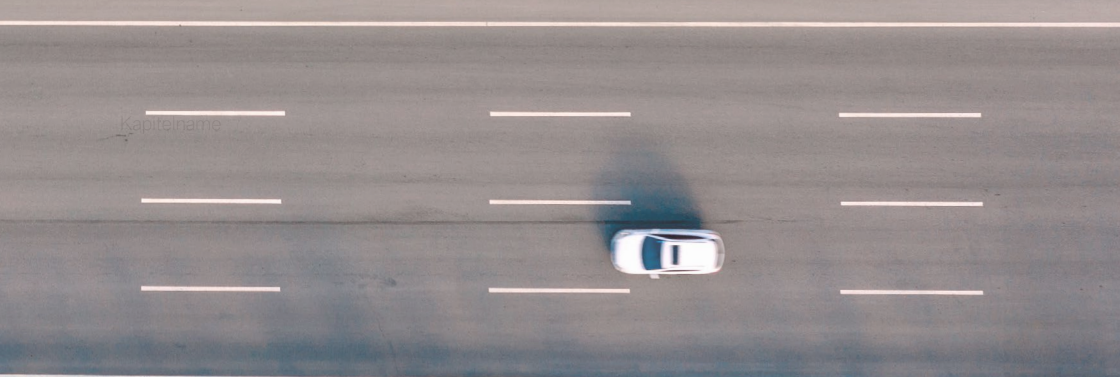
Once cars with self-driving mode are actively on the road amongst our everyday traffic, there will no longer be a need for the conventional manual drivers that we have today. Why? During the driverless ride there is no need for the passenger to be responsible for the constant monitoring of traffic or vehicle control elements in general. This is because the vehicle follows a program made by a human but controlled from outside of the vehicle by an attendant who takes on some of the functions and responsibilities that beforehand lay with the driver. Technical tasks can also be performed via digital environment systems that then form an integrated overall system with the vehicle. The Society of Automotive Engineers (SAE International) prefers the definition "cooperative driving" for cars dependent on communication and/or cooperation with outside entities such as those described above. In other words, we (humans) can set vehicles self-driving mode into motion and thus have overall control of the vehicle, at least by issuing commands that the vehicle then automatically implements.

A person can also take the vehicle out of traffic at any time. It is also important and necessary that we humans perform various functions in the maintenance and monitoring of the vehicle as well as being an accompaniment to the vehicle itself. Which functions and responsibilities lie within the vehicle system or the digital surrounding environment system and which lie with us as humans can differ greatly from system to system.



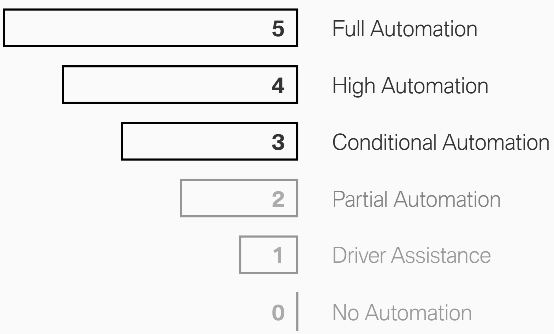
Autonomous means independent of a driver

Autonomous doesn’t mean self-governing, but rather self-sufficient and independent of a driver. The term “autonomous” can be translated from Greek as either “self-governing” or “self-sufficient.” Vehicles with self-driving mode do not drive in a “self-governing” fashion when in self-driving mode. They are directed by a code that programmers use to pre-determine the vehicle’s response. The program – and not the driver – thus determines the reaction of the vehicle in self-driving mode. Therefore, a more accurate translation would be “self-sufficient” in the sense that in most traffic situations the vehicle operates independently of human intervention and a driver does not need to constantly monitor or take over the system. This does not rule out a human switching off self-driving mode and then controlling the vehicle manually.

The level of automation doesn’t reveal everything

Levels of automation facilitate the classification of automatic driving modes of the vehicles. In order to assess their functions, however, a closer look at the different systems is required.

Automated vehicles have different levels of automation. The differentiation into these stages allows for a better understanding and paves way for the possibility of discussion of these vehicles. Internationally, the Society of Automotive Engineers (SAE) classifies road vehicles into six automation levels (SAE level 0-5).[1]



Autonomous vehicles (full automation) or vehicles with SAE level 5 would, according to this definition, be vehicles that are operated full-time by an automated driving system without any interference from a human driver.

"Such vehicles will not exist for at least the next 20 years."

Matthias Hartwig

Likewise, it is proving to be extremely difficult for current research projects to precisely classify vehicles designated as "autonomous" into SAE levels 3-5. Not just in research projects but also in everyday language and, for example, in the legal definitions of some American States. Therefore, the term "autonomous vehicle" is much broader. This text will discuss "motor vehicles with self-driving mode."

What is self-driving mode?

Self-driving mode is essentially dynamic driving in specific roadway and environmental conditions without human intervention. It can only be activated if the basic conditions are right.

Using the SAE levels, motor vehicles with self-driving mode in this context would best be classified as Level 4 (high automation). When self-driving mode is active, all aspects of the dynamic driving task under authorized roadway and environmental conditions are managed autonomously (self-sufficiently) by the vehicle. If the vehicle stays within its intended range of operation, no driver will be necessary. However, they cannot work independently “under all roadway and environmental conditions” as demanded by SAE Level 5. Hence the self-driving mode will be limited to specific roadway and environmental conditions and might depend on communication and/or cooperation with outside entities (for this, SAE suggested the definition of a cooperative rather than an autonomous vehicle). The system might even need to be monitored from outside the vehicle and with human technical back up in exceptional situations.

Humans continue to take over responsibility in the system

Although self-driving mode can replace the driver after its activation, it cannot replace all humans in the system.

If there is no driver for a vehicle, humans in other functions take on some of the responsibility instead. In recent research projects – and everyday language – vehicles referred to as “autonomous” often have a safety driver who intervenes in critical situations. In these vehicles, self-driving mode is still under development. The consequence of this is that the driver of such vehicles has more responsibility than a conventional driver. The authorities that mandate the piloting companies require such vehicles to have a fully attentive licensed driver with special training behind the wheel at all times. For example, when issuing a “Testing Permit,” the New York State Department of Motor Vehicles states that “A person holding a valid driver license must be in the driver’s seat while a vehicle is operated on public highways.

That person must be prepared to take control when required to in order to operate the vehicle safely and lawfully. Every test vehicle operator must be adequately trained in the safe operation of the test vehicle to ensure both legal and safe operation."[2] In the US, there is no vehicle currently available for sale that is self-driving.[3]

Even if in the future, with no drivers in the vehicle and the authorities not actively requiring one, there will be some sort of supervising vehicle attendant inside or outside of the vehicle. At the same time, the monitoring and maintenance staff at depots and in operating centers (or control centers) can play an important role. For a long time to come, those responsible – either inside or outside the vehicle – must be available to perform safety checks on the vehicle before start-up, to activate and deactivate the self-driving mode, and to guarantee reliable functioning while it's in operation. In exceptional cases, it may even be necessary for an "emergency driver" to take over operation on-site or remotely. Furthermore, the authorities expect the applicant for a vehicle permit to "submit with this application a law enforcement interaction plan to inform law enforcement officers and first responders how to safely interact with the […] vehicle(s) in emergency and traffic enforcement situations."[4]

The technologies behind the autonomy

For a vehicle to move without driver intervention, it must itself have a sufficient wealth of information. In order to obtain this information and to provide this relevant information to the vehicle, various technical developments outside the vehicle are required. The following table gives an overview of the technology that enables self-driving mode, making it easier to understand what these vehicles can do.

Information	Technologies
Driving order: The vehicle must “know” which destination it is expected to drive to.	• A human always determines the driving order. The vehicle cannot decide “autonomously” where it is going, the human must input the destination themselves in some form or another (e.g. “Drive to the next charging station”). • The digitalization of communication can help here, for example, apps and smartphones.
Self-positioning: The vehicle must “know” where it’s located.	Most of today’s transport positioning systems use the **satellite-based Global Positioning System (GPS).** GPS guarantees accuracy of positioning with deviations below eight meters. For self-driving mode, deviations of less than 5 cm may be required. This can be guaranteed by: • **Differential Global Positioning System (DGPS):** Reference stations on the earth eliminate GPS inaccuracies. • **Landmark and marker orientation:** If the system uses its sensors (camera) to recognize prominent landmarks whose position is stored in the system; they can position themselves with them. Road markings (center line) are also gathered to aid orientation.

Information	Technologies
Self-positioning: The vehicle must "know" where it's located.	• **"Virtual Rail" with Radio Frequency Identification (RFID) or other processes:** Small chips or other electronic orientation aids are applied in or on the road or in the road environment, which corresponding transmitter-receiver systems can detect electromagnetically to use for self-positioning. • If the speed and direction of travel of the vehicle are known due to vehicle data, a position change can be calculated.
Self-status detection: The vehicle must know a lot about its own status: Functioning of important systems, direction of travel, speed, door closing, indoor and outdoor temperature, etc.	Many different sensors provide this information: Odometers, rotation rate sensors on the wheels, gyrocompass, tire pressure sensors, door opening sensors, thermometer, etc.

Information

Roadway and environmental conditions: The vehicle must “know” how to reach its destination the fastest and safest way.

Traffic situation: The vehicle needs the exact position of buildings and other fixed obstacles, the current position, the outline, the speed, and the direction of movement of all road users in the area (cars, bicycles, pedestrians), traffic signs, traffic lights, etc. Only with a precise picture of the traffic situation can it also take into account all traffic regulations and avoid the endangerment of other road users.

Technologies

From static geodata (map data), to static traffic elements (traffic signs, construction sites), to traffic light signals, the position of fog banks, traffic congestion, individual cars, bicycles, and pedestrians, a motor vehicle with self-driving mode must have an accurate picture of its surroundings.

A **“Local Dynamic Map” (LDM)** stores the required data in the vehicle. Static information (e.g. map data) can be stored in the LDM in advance and compared with the actual environment in test runs on the intended route. However, data fed in this way requires constant updating. The LDM may obtain data from sensors on the vehicle itself or from sensors or digital services outside the vehicle. (➔ Illustration).

- To satisfy the high demand for data, the vehicle must be networked with its environment. The following serve as communication:
  - **Mobile communications:** The large amounts of data can be handled better with a high mobile standard. The currently much-discussed 5G mobile standard seems particularly suitable here given its high data transmission rates, real-time transmission, and low latency.
  - **Wi-Fi:** A wireless local area network (Wi-Fi) is being built by wireless modules on streetlights and sign gantries to improve communication.

Information

Roadway and environmental conditions: The vehicle must “know” how to reach its destination the fastest and safest way.

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Technologies

- Sensors in the vehicle or on the roadside detect the traffic environment and situation:
  - **Digital camera:** Cameras capture the environment optically, but may not detect everything (e.g. in darkness, fog, or backlight).
  - **Laser scanner/LIDAR:** The distance and speed of objects can be measured by using many laser beams. This allows for the creation of an accurate picture of the environment.
  - **Radar and ultrasound sensors:** Additional directional and distance measurement technologies complement the range of perception of other sensors and provide redundancy so that nothing is overlooked.
- **Sensor data consolidation and evaluation:** Different sensors and the images they have created and the data they collected have various advantages and disadvantages. Computers can use it to calculate a coherent picture that detects traffic much better than just one sensor.
- **Regional digital map:** Geodata and dynamic traffic data can be merged and refined in a vehicle-independent digital map. This data can be used by the vehicle.

Information

Roadway and environmental conditions: The vehicle must “know” how to reach its destination the fastest and safest way.

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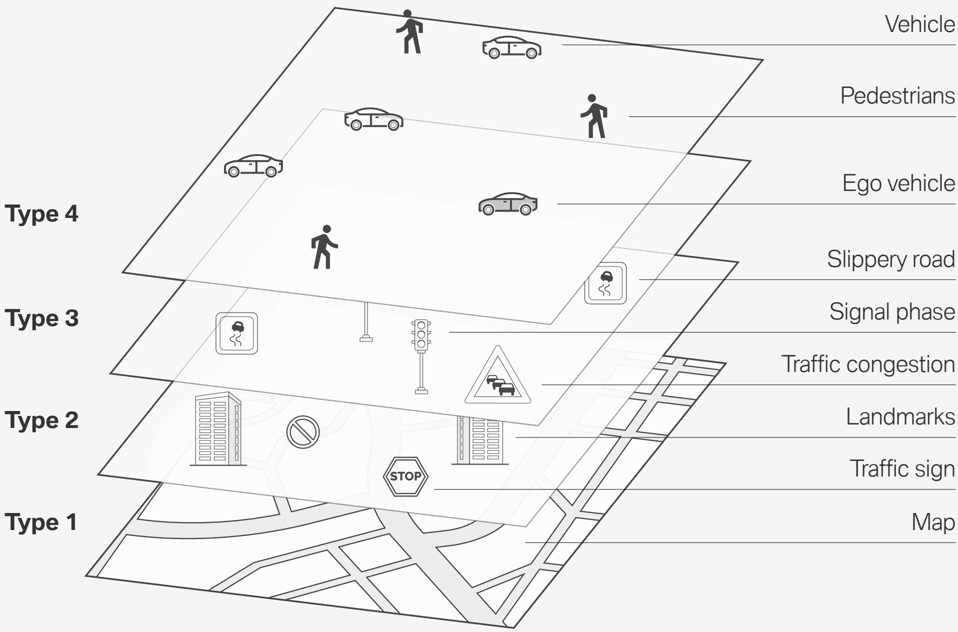
Technologies

- **Sensor data from other vehicles** (Vehicle-to-Vehicle Communication, V2V) can also be used, for example to supplement a regional digital map (e.g. traffic congestion information from other vehicles).
- **Digital traffic signs:** A camera cannot detect with sufficient reliability whether a traffic light is green or red. A digital radio signal from the traffic light can provide clarity in this case.
- **Control technology:** Brings together a large amount of data contained in an operator center in order to be able to centrally monitor and maintain the vehicle and infrastructure and coordinate the necessary interventions from outside.

Example of a “Local Dynamic Map”



Type 1: Permanent static data (map data)

Type 2: Transistent static data (roadside infrastructure)

Type 3: Transient dynamic data (congestion, signal phase)

Type 4: Highly dinamic data (vehicles pedestrians)

Powerful computer programs and artificial intelligence

In particular, the merging and evaluation of sensor data requires the use of powerful computers and complex programs. In this case, artificial intelligence can also be used.

What does artificial intelligence mean?

Artificial intelligence describes the ability of a computer program to extract logical correlations from large amounts of information (pattern analysis and pattern recognition) to draw conclusions according to certain rules (i.e. predicting patterns).

These processes are often used in image recognition and image analysis. For example, if a computer program has already analyzed tens of thousands of images of different models of cars, it will be able to identify a car as such even if it has not “seen” the specific model before. Accordingly, if the computer program has analyzed many vehicles turns, it can predict the course of a turning vehicle with certain probabilities. This ability is very important for self-driving mode since the systems are better able to navigate in unknown surroundings and constellations. Independent and ethically thought-out decisions, comparable to those of a human being, cannot be made by such systems. Therefore, the term “artificial intelligence” may give rise to partially exaggerated expectations.

Cooperative driving: From vehicle system to integrated overall system?

The self-driving vehicle system of a car with self-driving mode may, in certain circumstances, rely on digital surrounding environment systems (cooperative automation).[5] From a technical point of view, the vehicle system with digital surrounding environment systems can also be considered as an integrated overall system. This overall system must meet certain requirements to ensure optimum results for traffic safety and traffic flow. Autonomous driving (SAE: cooperative driving) requires a change of focus from the vehicle to an overall system because it will only achieve adequate performance in various traffic situations in close cooperation with digital surrounding environment systems. For example, when driving through traffic lights at a complicated intersection on-road sensors and digital signals from the traffic lights themselves would be needed at a red light to ensure safety and accuracy.

We are accustomed to associating cars almost as a uniform or a distinct tool used by a driver. This distinction is common to all traffic and vehicle safety regulations in every country. In the US the National Traffic and Motor Vehicle Safety Act[6] regulates motor vehicle safety and mandates the application of the Federal motor vehicle standards[7] regarding design, construction and performance of all motor vehicles.[8]

Then again the rules of the road are regulated by the Federal States and address the driver only, who must control his tool and is responsible for every action of the vehicle itself. If the driver in the vehicle becomes just a passenger, this division can no longer work. Car manufacturers must comply with Federal Motor Vehicle Safety Standards and certify that their vehicle well aligned with safety features to avoid risks under all circumstances and in all driving modes. For motor vehicles with autonomous motion functions this includes to ensure that they operate in compliance with the rules of the road.[9]

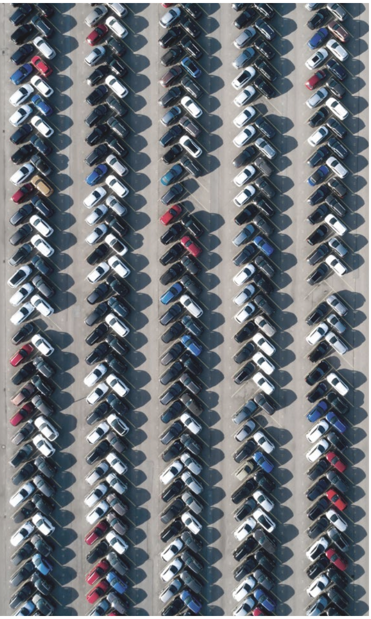
The concept of the vehicle as a definable tool must also be questioned. Whether a vehicle with self-driving mode can handle its driving task safely and smoothly will increasingly depend on information originating from various digital surrounding environment systems (digital traffic signs, regional digital map, roadside sensors, etc.) (cooperative driving systems). The vehicle drives based upon its own digital map, which it continuously updates with the help of information from outside. The vehicle is not always able to decide on its own whether this data is reliable or not. It has to rely in part on the surrounding environment system. The U.S. Department of Transportation states that cooperative automation will be "an important complementary technology that is expected to enhance the benefits of automation at all levels, but should not be and realistically cannot be a precondition to the deployment of automated vehicles."[10]

"I think that SAE Level 5 will remain a dream for quite a long time, but SAE Level 4 Technology V2V and V2X will be very beneficial and more important than what the current discussion implies for the majority of valuable use cases."

Matthias Hartwig

Traffic light example

- A vehicle cannot detect a conventional traffic light with a camera with enough reliability.
- It can only drive quickly at an intersection if it gets a digital traffic signal.
- However, this signal only has an added value if the traffic light operator guarantees its reliability.
- The vehicle is thus increasingly cooperative with digital surrounding environment systems.



Parking garage example

- A parking garage designed for self-driving valet parking could soon be possible using comprehensive data where cameras and other sensors detect free parking spaces, vehicles, and pedestrians into a dynamic traffic map (technical surrounding environment system).
- Navigating becomes very easy for the motor vehicle in self-driving mode here. However, it must be able to rely on the given information. Not only does the vehicle have to be safe, but the vehicle and surrounding environment system must form a secure overall system to prevent accidents together.
- At a certain point, the question arises as to who is actually in control of the vehicle – the vehicle or the parking garage.

The vehicle and the surrounding environment system would technically form an overall system. Only if this overall system is safe and provides enough valid data for navigation will the vehicle be able to safely navigate and run smoothly through traffic. In order to ensure the identifiability of those responsible, there must be continual legal areas of responsibility. As a result, in the future it is likely that there will be system administrators for the vehicle whom will monitor the various digital surrounding environment systems. Technically, a single system in isolation would often lead to a dead end as the required amount of safety precautions along with the monitoring of traffic flow can only be provided when there is an interaction of all components. Some expect this to result in a system approval process with very complex verification processes and accountability obligations. The emerging regulatory challenges are closely connected to the regulation of Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure communication (V2X). No country has presented a regulatory approach for this technology as of yet. Car manufacturers have to petition for legislation as they can't guarantee the safety of the integrated overall system on their own, while their vehicle is only a subsystem.

Manual, automated, and self-driving mode. What does this mean?

While a variety of terms are used to describe automated vehicles and their driving modes, many experts and legislations identify three: manual driving, automated driving (sometimes called autonomous driving), and self-driving (sometimes called fully autonomous). These are 3 different driving modes with different regulatory and technical requirements. In this case, a single motor vehicle can have both a manual, an automated, and a self-driving mode.

Manual driving mode

Until Nevada authorized the operation of autonomous vehicles and endorsed a driver license for operators of autonomous vehicles, all traffic regulations in the US only referred to manual driving. It was never referred to as anything else, because until recently it was obvious that an alert driver would have to steer the vehicle at all times. Some driver assistance systems had already been regulated under the Federal Motor Vehicle Safety Standards (FMVSS), since from a regulatory perspective a driver assistance system doesn't change the customary distribution of tasks between the human driver and the technical system. The driver remains responsible for driving the vehicle in every situation. They must observe traffic at all times and maintain control of the vehicle.

Automated driving mode

Since 2011 legislation and executive orders have regulated the operation of automated vehicles on public roads in 41 States. Not only the first bill in Nevada, but all regulation requires a licensed and specially trained driver to be present in the vehicle, to monitor the vehicle and the traffic, and to be ready to take over control of the vehicle if necessary at all times. This driver still has the responsibility of a conventional driver and must comply or guarantee compliance with all rules of the road and traffic regulations, even during the automated journey. If the driver notices that his vehicle in the automatic driving mode violates regulations of the rules of the road and traffic regulations, they must deactivate the system and take over control. The system must independently register relevant deviations and then prompt the driver to deactivate the system. The greatest challenge for the developers of such vehicles is therefore to permanently maintain and control the attention of the driver, as it is still essential to the system. In aviation automation the demands are even higher with it being mandatory to have two piolets present in each airliner. In both pilots monitor each other respectively. A corresponding development for motorized, private transport on the road, however, is ruled out. The freedom of Americans to drive their own vehicles by obtaining a driver license should not be further limited due to excessive skill or intellectual requirements. Even today, for some it is not easy to obtain a driver's license, this problem should not be exacerbated by automation.

What is private transport?

Private transport usually means one person using a means of transport. Unlike public transit, this person determines the time period, the route, and the destination themselves. The most classic means of motorized private transport is the car.

Self-driving mode

There is no legal framework for the use of motor vehicles with self-driving mode on public roads. “Every vehicle currently for sale in the United States requires the full attention of the driver at all times for safe operation.”[11] Under the current FMVSS, no self-driving mode can be introduced according to any interpretation of the rules and exemptions from existing standards. The National Highway Traffic Safety Administration (NHTSA) can provide exemptions from existing standards, but only for limited exceptions in obligation to comply with the FMVSS.[12] The FMVSS do not apply to motor vehicles “solely for purposes of testing or evaluation by a manufacturer that agrees not to sell or offer for sale the motor vehicle at the conclusion of the testing or evaluation.“ However, testing vehicles on public roads under this special condition leaves the manufacturer with an uncalculated risk of liability and doesn’t contribute to the development of proper legal framework for vehicles with self-diving mode. Therefore, the U.S. Department of Transportation has promised while prioritizing safety to “modernize or eliminate outdated regulation that unnecessarily impede the development of automated vehicles or that do not address critical safety needs.”[13] Having said this, a clear commitment to regulate vehicles with self-driving mode does not exist, because this would mean a paradigm shift in transport regulation. The driver may no longer be considered in the development of such a self-driving mode. They are instead responsible for monitoring the system and assuming a fallback responsibility.

This circumstance requires a completely different system architecture of the vehicle. In self-driving mode, the vehicle must be able to solve all standard traffic situations it may encounter on its own. If the subsystem were to fail or in other exceptional situations, the vehicle must remain able to steer into safety (for example, to safely stop on the roadside). Human intervention may be necessary in clearly defined cases such as:

- During maintenance
- During activation
- In extraordinary traffic situations
- In exceptional situations
- After deliberate deactivation of self-driving mode by a person

However, the vehicle must be designed so that a certain amount of time can elapse before the human helper takes action and it must not become a traffic obstacle during this waiting period.

“The developers of such vehicles must ultimately consider – and to a certain extent anticipate during development – any possible traffic situations that may require additional help.”

Matthias Hartwig

The local limitation in the field of application plus the careful selection and design of the route can limit this complexity. For example, if a shuttle for a regular service is being developed by a local transport operator in a small residential area in a 30 MPH zone, a very detailed digital map can be maintained for this area, into which all traffic signs and regulations have already been entered in. If for example it is found that the vehicle is not able to overtake garbage trucks for some reason, the vehicle simple does not operate at the times during which garbage is picked up in the residential area. Alternatively, it can contact an operator center in time to authorize uncommon maneuvers. Such situations can be easily anticipated and planned for in a small-scale area. If the vehicle should nevertheless get into an unpredictable traffic situation, it can drive to the side of the road and wait for employees from the operator center to arrive.

Vehicles with several driving modes

In just a few years, there will be vehicles that can be controlled manually by a driver as well as having automated and self-driving modes.

Example: BMW 3 Series with various driving modes

A **BMW 3 Series** with parking, traffic jam assist, and cruise control is already state-of-the-art. In a few years, additional assistance functions provided by the vehicle will be highly reliable even at higher speeds and there may even be talk of a highway assistant. Intervention by the driver would only be required in certain circumstances. The driver remains part of the system but is adequately guided to a necessary intervention (automatic driving mode). At the same time, however, it will still be possible for the driver to take over control of the vehicle, with only the driver and emergency assistance functions remaining active (manual driving mode).

Furthermore, it is quite realistic that the parking assistant is then capable of so-called autonomous valet parking. The BMW 3 Series may be able to park itself – if the respective parking garage support this function. If both the vehicle and the parking garage offer this coordinated function, the driver exits at the barrier to the parking garage.

In close coordination with the parking garage's digital surrounding environment system, the vehicle takes over the journey to the parking space on the third floor. This self-driving mode could increasingly be used in other environments over the years, so long as it offers a corresponding digital surrounding environment system. The prerequisite for the activation of the self-driving mode will always be that the surrounding environment system is compatible, the vehicle is active and functional, and that the vehicle registers itself there.

The BMW 3 Series from this example would not be a manual, automated, or self-driving vehicle, but rather a motor vehicle with all three driving modes incorporated. In each of the three driving modes, the vehicle developers and the driver must take the specific regulations into account.

Self-driving mode needs its own regulations

Manual, automated, and self-driving modes each need their own regulation. While the first regulation of manual driving coincided with the introduction of the first automobiles, the States started to regulate the operation of automated vehicles in 2011 and the U.S. Department of Transportation (U.S. DOT) published the first Federal Automated Vehicles Policy in Sept. 2016.[14] NHTSA, in contrast to manual and automated driving modes with self-driving mode the driver is no longer the reference point for regulation. Self-driving mode is also unable to simulate a human driver. Therefore, unique legal regulations based on the existing traffic law and ethical standards are necessary for this driving mode, but they must also take into account the technical conditions.

The "U. S. DOT automation principals" "will interpret and […] adapt the definitions of 'driver' and 'operator' to recognize that such terms do not refer exclusively to a human, but may in fact include an automated system."[15] This means that when in self-driving mode the vehicle is the driver and needs to comply with the rules of the road in the same way a human driver would. Legal regulations are always used as instructions to people who interpret human laws (judges and decision-makers in business and administration). The requirement that an automated system ought to simulate the human driver is formulated here in an exaggerated fashion. This regulation makes sense for automated driving, because in this case a driver is constantly responsible for the system and must be able to take over control of the vehicle immediately in crisis situations. This driver will judge the system according to whether it is reacting in traffic situations as they would themselves.

What can humans do and what can machines do?

Humans and machines are too different in their reaction times and in how they perceive and analyze traffic situations for the application of the same set of regulations to make sense in each case. Humans have an intelligence that machines cannot simulate coupled with excellent image recognition and the ability to analyze situations. This is complemented by intuition and the ability to independently evaluate situations in terms of ethics, which machines lack. On the other hand, machines have an almost unlimited information processing capacity along with multitasking capabilities, which are ultimately limited only by the amount of information available to them. In terms of positive reactions, humans are able to demonstrate flexibility and therefore personal responsibility yet machines can react in a fraction of a second and can demonstrate superior reliability (adherence to a program). Self-driving modes therefore need their own guidelines for their development incorporated into the FMVSS. This must include the rules of the road and traffic regulations as it reflects legitimate expectations of other road users in mixed traffic. For example, self-driving vehicles should also stop at a red light, even if they have reliable information that no other vehicle is driving through the intersection. Otherwise, this would be a bad example. Apart from this, these regulations should be geared toward the capabilities of a machine and guided by optimal results for traffic safety and traffic flow.

Reviewing and modifying traffic laws and regulations of the States

A vehicle in self-driving mode cannot be addressed by any law or regulation, because they only apply to humans. Therefore, the safety of the self-driving strategy and reaction of the vehicle on the road must become subject to the FMVSS standards. But in the US, traffic is regulated by State law. This leads to the question of which State law should guide the FMVSS? This again shows that the rule of “self-driving vehicles should follow the rules of the road” is not very practical, because it would force the developers of a self-driving mode to look at the traffic regulations in all the States and territories in depth and (where appropriate) develop different driving software for different States. The U. S. DOT therefore already announced it “[u]rges States and localities to work to remove barriers […] to automated vehicle technologies and to support interoperability.”[16] As for self-driving mode, it should further review the rules of the road in all States and territories and develop technical standards that include the most important common rules whilst encouraging regulatory consistency for interoperability. The States will lose some of their regulative power because a vehicle in self-driving mode is not and never will be a human capable of complying with traffic regulations. The only chance for a common technical standard and interoperability is to open up the State traffic regulations that do not apply to vehicles in self-driving mode and trust the U.S. DOT and NHTSA to do a good job.

The Goal: More sustainable, safer, and efficient mobility for all

Next chapter

Motor vehicles with self-driving mode promise sustainable, safe, and efficient mobility for all. If and when this promise will be fulfilled depends on various factors.

With the support of the U.S. DOT, the State governments, and the European Union, not only large car companies but also many previously unknown companies new to the automotive industry (e.g. big data companies) are investing billions in research into motor vehicles with automated and self-driving modes and into the development of a digital surrounding environment for these vehicles.

Opportunities for traffic and the job market

All parties involved believe that motor vehicles with self-driving mode can contribute to the achievement of the following objectives:

Increasing the safety of traffic[17]

Ninety-four percent of all serious motor vehicle crashes "are due to human error or choices. Fully automated vehicles that can see more and act faster than human drivers could greatly reduce errors, the resulting crashes, and their toll."[18] Connected vehicles with automated or self-driving modes can absorb and process much more information in less time than a human driver and they do not get tired and are never drunk. They will not miss a digital traffic light and they can even look around corners to reliably detect complex traffic situations at intersections through roadside sensors. A majority of the sources of errors that are the cause of traffic accidents today can be excluded.

However, automatic systems can and must be designed so that potential errors do not lead to life-threatening injuries or illnesses, and so that new sources of errors can be avoided. Motor vehicles with a self-driving mode can only be certified under the FMVSS and can only be registered if they avoid personal injury as much as is technologically possible and thus significantly reduce accidents when compared to human driving performance. The first U.S. DOT principle of automation therefore declares “We will prioritize safety.” Despite the very technology-friendly approach of the U.S. administration, the protection of the public “against all unreasonable risk of accidents occurring as a result of the design, construction or performance of motor vehicles”[19] will always be the guiding principle for the road agency. As soon as vehicles with automated and self-driving modes can contribute to safety, they will take on an essential part of this protection strategy. Until then, high safety standards will be the challenge developers have to face.

Increasing the traffic flow and traffic efficiency

Human error and a lack of information lead to a large part of traffic disruption. If available, automatic and cooperative systems can incorporate an almost unlimited amount of information for optimized driving and route guidance.

Whether motor vehicles with automated driving mode increase or inhibit the flow of traffic largely depends on the abundance of geo-information and traffic information made available to them, as well as the development of on-board and roadside sensors and digital surrounding environment systems. A large amount of the required information is already available on the Internet. Weather services can now deliver valid weather data for cooperative driving. However, this validation remains a big challenge for map and traffic data all the way down to digital traffic lights. In addition, the roadside sensors for detecting the traffic and the parking situation (data-saving example, by radar and LIDAR) are not free, but promise a big increase in traffic efficiency in conventional parking spot searches. In research projects, for example, cities and municipalities are beginning to recognize new duties and design possibilities. In cooperation with private data companies, they could issue regional dynamic maps complemented by digital mobility platforms for their region, offering validated map data with information about traffic regulations, construction sites, enrich dynamic traffic data, and make it available for automated and self-driving modes as well as cooperative driving. This is an optimistic vision of the future, but with some political will it is certainly feasible.

Creating new economic opportunities and jobs through technological modernization and innovation[20]

The global market for vehicles with self-driving mode is expected to reach $54.23 billion in 2019 and $556.67 billion by 2026, an average growth rate of 39.47 percent.[21] U. S. DOT expects that “with the development of automated vehicles, American creativity and innovation hold the potential to once again transform mobility.”[22] The loss of jobs (e.g. bus drivers in public transit) is not to be feared in the coming years. Self-driving modes will only be able to handle more and more traffic situations gradually over time. Drivers will continue to be needed in dense city traffic, on the highway, and for large buses on major routes. However, the use of vehicles with self-driving mode could provide increased passenger numbers to public passenger transport and ride-sharing solutions. Self-driving minibuses can bring more passengers to central stops and make public transit and shared mobility more attractive. Even more, not fewer, drivers would probably be needed on the main routes. In addition, self-driving mode offers potential for more jobs in research, development, and maintenance. Control centers will also need staff who can monitor the vehicles and, in exceptional circumstances, quickly dispatch a technician to the job site, similar to the call centers of passenger elevator service providers.

> **“In addition, self-driving mode offers potential for more jobs in research, development, and maintenance.”**

Matthias Hartwig

New potential uses for the vehicle itself

A motor vehicle with self-driving mode has the potential for users to use the ride itself for both personal and work-related tasks. Commuters in particular may stand to regain a lot of time that was previously tied up with the task of driving. On the way to the office users could begin dealing with emails or watch a movie on their way home.

The opportunities for sustainability

Many also hope that motor vehicles with a self-driving mode will also fulfill the following three promises. However, whether these can be realized depends on the right course of decision-makers in politics and business and on early and effective regulation by the legislature.

Zero-emission transport

According to the Paris Agreement on Climate Change (2015), the increase in the global average temperature should be limited to well below 2 °C above pre-industrial levels. Certain efforts are expected to limit the temperature rise to 1.5 °C above pre-industrial levels. Although the US is no longer committed to the agreement, climate protection will remain on the US and the international agenda. In particular, greenhouse gas emissions (carbon dioxide, methane, nitrous oxide, and others) are expected to be significantly reduced.[23] Integrating climate action into national policies, strategies, and planning[24] and is expected to significantly reduce the risks and impacts of climate change.

In many sectors (heat generation, agriculture) it is more difficult to reduce greenhouse gas emissions than in the transport sector. Therefore, most experts agree that direct emissions from transport must reach zero in the long term in order to achieve the goals of the Climate Change Agreement (known as zero-emission transport). In addition, transport is known to be responsible for environmental and health issues caused by particulates, nitrogen compounds, and other emissions. Also, for this reason, zero-emission transport is an important political goal. The increase in traffic flow and traffic efficiency through the use of vehicles with self-driving mode is already able to make a proportionate contribution to reducing emissions, but in itself will not ensure zero- emissions transport. This requires, moreover, that all vehicles with self-driving mode are operated only with electricity from renewable sources (electric vehicles with batteries or fuel cells). Self-driving mode and battery-based electric engines also fit well together because the vehicle itself knows when it has to be charged and can automatically connect to a charging station. Therefore, most national and international projects on vehicles with automated and self-driving mode deploy electric vehicles. Automation, digitalization and electrification of transport are grouped together by experts.

Access to safe, affordable, accessible, and sustainable transport systems for all[25] and non-discriminatory transport[26]

If politics and economics pave the way, self-driving shuttles and similar vehicles with limited specific driving and local applications can enable local passenger transport in the near future, bringing everyone from door to door at any time. Properly designed, such a transport system would be able to cope with much fewer vehicles and hardly require parking (only stops). This has great potential for urban planning and the use of space. Areas currently used by traffic could have new uses (parks, playgrounds, cafes, etc.). A self-driving shuttle can also be programmed to treat all people equally, regardless of gender, age, ethnicity, sexual orientation, and physical characteristics or limitations. By taking socio-scientific insights into account, the feeling of safety for passengers could increase considerably. This can be accomplished, for example, by appropriately designing the vehicle, system, the stops, and the route guidance. This, too, has great significance for non-discriminatory transport.

Today's transport system focuses on motorized private transport. Especially in rural areas, therefore, all the people who are too young, too old, or too sick to drive their own car, or cannot afford one, are often excluded from mobility or dependent on someone else with a driver license. Motor vehicles with a self-driving mode can end this dependency by making conventional and new forms of public transit comprehensive and affordable for all municipalities.

More space for people, less space for transport, less resource consumption

Mobility for all promises an enhanced quality of life. Cities and towns whose streets and squares are used exclusively for driving and parking offer a lower quality of life. Asphalt road surfaces damage the soil and encourage flooding.[27] Motor vehicles with self-driving mode – in conjunction with existing public transit – can provide convenient, reliable, and efficient door-to-door mobility for all and play an important role in local logistics.

> **"In this way, it may often be easier for many people to go without their own car."**
>
> **Matthias Hartwig**

Fewer vehicles will be in use for package delivery services as well. In addition, decreased traffic volume and an automatic assessment of the traffic situation result in better time management and fewer traffic jams. In addition, in a digital traffic system, vehicles can proactively adapt their speed to the traffic situation and find parking and stopping spaces without search traffic. Self-driving modes thus transform the cityscape hand in hand with digitalization. In addition, fewer vehicles means less resource consumption elsewhere.

The risks of data misuse and access opportunities

Automation and networking of transport also entail risks. If motor vehicles with self-driving mode are improperly used, the worst would be increased traffic volume, increased emissions, and unequal mobility opportunities. In addition, manufacturers must do everything they can to prevent possible hacker attacks on vehicles and to ensure the security of the data. Motor vehicles with a self-driving mode can be misused for data collection and could be attractive targets for hackers. A look at China reveals further risks: China is currently testing a rating system with social points for all Chinese citizens, which could also decide on their access to public mobility services. The possibilities of abuse of this kind must be effectively and comprehensively counteracted in the USA by consistent regulations for data protection and data security. Research into motor vehicles with self-driving modes also increases the need for discussion for the possibilities of abuse and possible solutions to such issues.

In Conclusion: A new mobility landscape?

Next chapter

Self-driving valet parking, self-driving public transit shuttles, as well as self-driving DHL Packstations and street cleaners – there are numerous possibilities.

As mentioned above, at present motor vehicles with self-driving mode cannot overcome every possible traffic situation without human intervention. Certain situational circumstances will continue to require human control. Drivers are still needed on the highway at high speeds or at least in dense city traffic.

In a few years, however, there will be self-driving modes that are capable of handling more and more traffic situations without the intervention of the driver. In close cooperation with a digital surrounding environment system, for example, they will be able to enter and exit a parking garage and park in one of the available parking spaces (self-driving valet parking). Various locally and functionally limited deployment scenarios are conceivable in passenger traffic as well. Over the years, the areas and fields of application will continue to grow. With self-driving taxis (robo-taxis) in limited operational areas, sharing providers may be able to largely cover their current business areas within 20 years and thus complement their car-sharing offer. There could even be a combination: If you want to drive the robo-taxi yourself, you can scan your driver license and get started. Through multimodality and the digitalization of communications (apps and mobility centers), motor vehicles with self-driving modes can become part of high-performance public transit with door-to-door mobility. Buses with drivers will continue to handle traffic on the main routes on the highway and in dense city traffic. Streetcars and commuter trains are also (in part) suitable for the use of self-driving modes.

Outlook for private transport

You will not be able to buy a car for quite some time that is able to overcome every conceivable traffic situation, including on ordinary roads, without human intervention. However, passenger cars in private transport will soon be available for sale with situationally limited functions such as self-driving valet parking or highly automated driving on the highway. Perhaps in the next few years, cities and municipalities will also equip (individual distinct) areas with digital surrounding environment systems that allow self-driving mode for all public transit. Correspondingly equipped private cars could then possibly use such systems for a fee. In complex, dangerous traffic situations – such as on highways or in dense city traffic – in private vehicles with self-driving mode, drivers will still have to control the vehicle for quite some time.

Prospects for commercial vehicles and company transport

Likewise, the use of vehicles with self-driving mode in the field of commercial vehicles and company transport offers many opportunities. For example, self-driving DHL Packstations or street cleaners that drive at night on empty roads to their job site are certainly conceivable. Such applications may be possible in just a few years as they do not require high speeds and would therefore be easier to implement. In addition, a variety of operational applications for motor vehicles with self-driving mode are conceivable. In the near future, ports will be handled by self-driving cranes, forklifts, and transport vehicles and in warehouses, motor vehicles with self-driving modes will soon become part of everyday life. A few years ago, airports began to gain experience with self-driving vehicles not only in passenger transport, but also in baggage handling. The potential for safety, sustainability, and efficiency through autonomous driving functions are high in these areas.

The relevance of self-driving mode for traffic safety and their economic opportunities is very high. In addition, they are very promising in terms of gains in comfort and lifespan. Whether motor vehicles with autonomous driving functions will also fulfill their great potential for environmental and climate protection and whether they will keep the promise of equal mobility in less traffic and whether affordable and non-discriminatory mobility will be possible for all remains to be seen. It seems possible with a bit of political will. Motor vehicles with self-driving mode can then make a significant contribution to better mobility for all.

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