Global IT Innovator

When the car takes over

a glimpse into the future of autonomous driving

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THE AUTONOMOUS VEHICLE IS COMING

. . .

… there's no doubt about that. We just need to ask:

WHEN
will the first autonomous vehicles appear on roads?

WHEN
will self-driving cars (SDCs) outnumber other cars?

WHEN
will only self-driving cars shape the streetscape?

?

What technological and legal prerequisites must be fulfilled or must first be established? What can (and must) the automotive and supplier industries do now to set the course for the future – a future that belongs to autonomous driving?

This NTT DATA white paper provides answers to these questions. Our company has had a clear focus on innovative IT solutions for the automotive industry for over half a century. In three scenarios for 2020, 2050, and 2060, we have outlined a series of changes that autonomous driving will entail – for the driver as well as the automotive and supplier industry. We are also focusing on key points such as the complete remodelling of the passenger compartment, the increasing importance of car-sharing, and fundamental changes in aftersales.

In addition to the three future scenarios, we will address the fundamental elements of autonomous driving in terms of technology, safety, and legislation.

We hope that this will provide you with more insight into the future of autonomous vehicles.

I. THE EVOLUTION OF AUTONOMOUS DRIVING

When talking about autonomous driving, it should be pointed out that “autonomous” does not necessarily mean that a vehicle drives self-sufficiently without a driver. Different manufacturers or public institutions use different levels of automation and autonomy. In this white paper, we refer to the following classification based on Standard SAE J3016:

1. Levels of ‘auto-nomy’

The different evolutionary levels of autonomous driving

0 **LEVEL 0**
only the driver is in charge – no intervening system is active

1 **LEVEL 1**
assisted driving – individual functions are supported

2 **LEVEL 2**
partially automated driving – multiple functions are supported

3 **LEVEL 3**
automated driving – automated driving in special situations (traffic jam, highway) is possible – driver must intervene if necessary

4 **LEVEL 4**
highly automated driving –automated driving possible in most situations; emergency program in case the driver does not respond

5 **LEVEL 5**
fully automated driving – driverless driving

Except for classic and vintage cars, all vehicles have reached Level 1 – most of them even Level 2. Functions such as dynamic distance control, emergency brake, or lane departure warning systems are already available in premium models. Automated parking is also available in many models. From a technical point of view, vehicles are available for Levels 3 and 4 and may soon be released to the market, depending on general conditions. Many manufacturers plan to enter the market in 2020. However, it will probably take quite a few more years for Level 4 vehicles to go into series production. In our opinion, distribution in the premium segment will start around 2050.

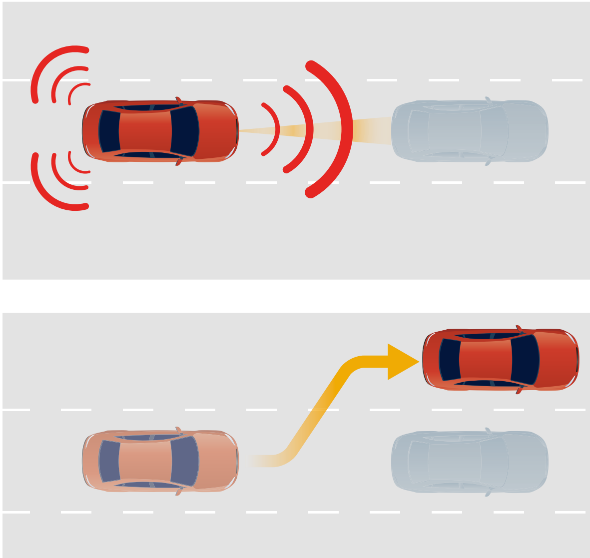
2. Central functions of self-driving vehicles

PROACTIVE ROUTE OPTIMIZATION

Using the Internet connection and precise location and traffic data, the artificial intelligence of a self-driving vehicle can optimize the route ahead, avoid congestion and reduce travel time. The data can also be used to determine the optimal start time in order to arrive at the destination on time. It's possible that a start window will be assigned, similar to air traffic.

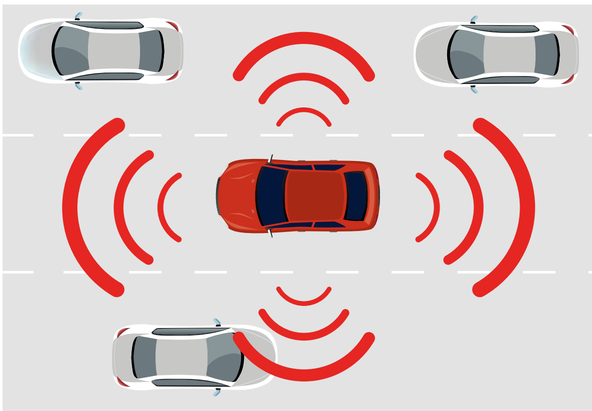
COLLABORATIVE TRACK CHANGE OR COLLABORATIVE TURNING

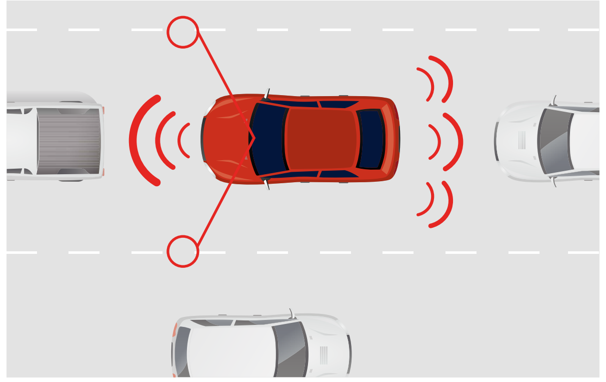
The system searches for a gap by radar, laser or camera to safely change lanes or turn. Before the system can start the process, it must communicate the lane change or turn manoeuvre to nearby vehicles – by indicating or car-to-car communication.



COLLISION AVOIDANCE

The system is based on radar, laser or camera technology that prevents collisions on the basis of a continuous 360-degree environmental check (other vehicles, pedestrians, bicycles). The system initiates emergency braking or manoeuvres when a collision looks imminent.



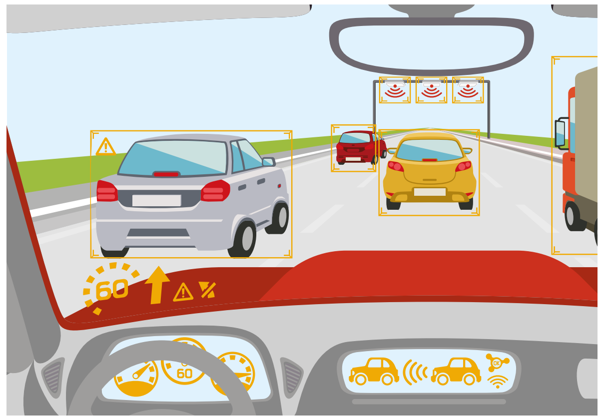


LANE TRACKING ASSIST

Without human control, the self-driving vehicle needs functions to keep its lane: Sensors or cameras must detect the lane and keep the vehicle within the lane mark. They must react quickly to unusual movements of the vehicle and put it back on track.

TRAFFIC SIGNAL AND TRAFFIC SIGNAGE IDENTIFICATION

The self-driving vehicle must recognize traffic signs and traffic lights and follow the rules. This can be done by cameras that can detect traffic lights or signs, or by car-2-X communication where traffic lights or street signs send information directly to the vehicle. In the future, the vehicle could also receive dynamic traffic information from a central location.

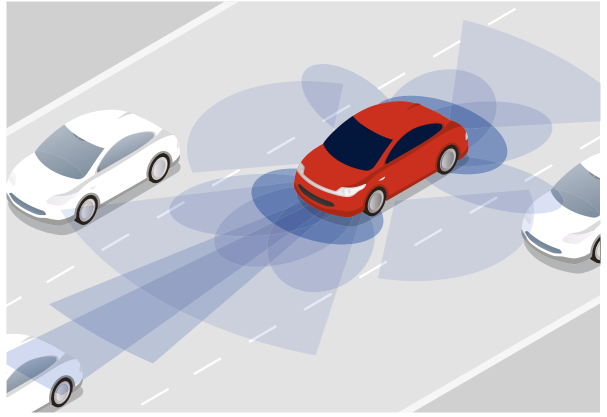


COLLABORATIVE SPEED CONTROL

With radar sensors, the vehicle measures the distance to obstacles and other vehicles in the area. With sensor data, the technology can adjust the speed to the traffic situation and predict sudden speed changes due to surrounding influences. It is thus possible to maintain a safe distance and adjust the speed accordingly – for optimal traffic flow.

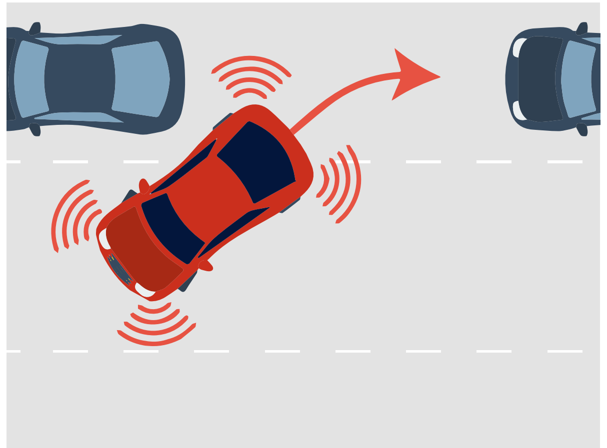
AUTOMATIC DISTANCE

Radar sensors measure the distance to the next vehicle. Sensor data ensure that the vehicle adapts its speed to the vehicle ahead. So there is always a safe distance and the speed rules are met.



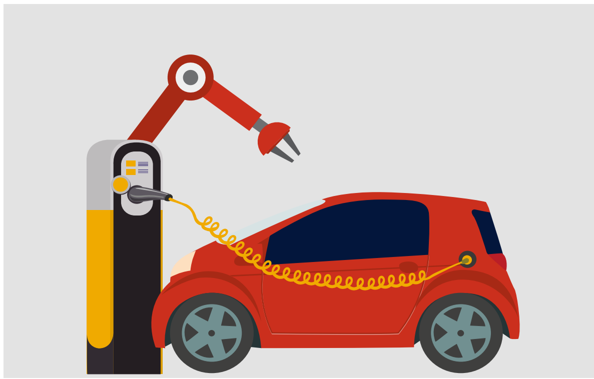
AUTOMATIC PARKING

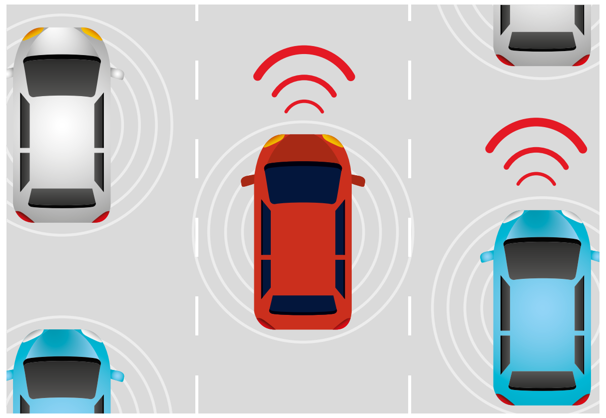
With the help of cameras and ultrasound technology, the vehicle finds a parking space and parks on its own. By communicating with the connected car backend, the car is always informed of current or predicted available parking spaces.



SELF-FUELLING / SELF-CHARGING

Self-propelled vehicles, whether electric or (still) petrol-powered, drive independently to the charging station or petrol station. Refuelling is then either by a human or by robotic systems that connect power plugs or fuel nozzles to the vehicle.





COLLABORATIVE PASSING

A vehicle communicates a planned overtaking manoeuvre to the surrounding vehicles. These adapt their behaviour accordingly, so that the overtaking procedure can be done easily.

DRIVING IN CONVOYS (PLATOONING)

Several vehicles (especially trucks) drive close behind each other to reduce fuel consumption through reduced air resistance.

MAINTENANCE AND REPAIR MANAGEMENT

Fully automated vehicles can detect when a repair or maintenance is needed on its own and manage it autonomously. The vehicles can order spare parts, make an appointment with the workshop and go there by itself. The billing and payment process can also be almost completely automated – after approval by the owner.

OVER-THE-AIR SOFTWARE UPDATE

Regular, over-the-air software updates - for new functions, more customer benefits and, above all, more security.

NEW BUSINESS MODEL

Car-sharing platforms for autonomous vehicles will emerge. Users can book vehicles and autonomous vehicles can continuously update their expected availability.

FUELLING AND CHARGING

Autonomous vehicles will be self-refuelling or recharging. This will be done by induction or by robots at the charging station or gas station.

PRIVATE OWNER AND FLEET OPERATOR

In the future, more vehicles will be fleet-owned than privately owned. Driving becomes a mobility service.

RENT 4 DRIVE

DriveShare

CYBER SECURITY AND CONFIDENTIALITY

Protection of vehicle IT and networked backend systems against hacker attacks as well as protection of personal data and the privacy of the occupants.

TRAFFIC INFRASTRUCTURE

In the world of autonomous driving, traffic infrastructure can be kept to an absolute minimum. Because the cars always know the latest virtual signage.

NAVIGATION

Using a high-precision satellite positioning signal in combination with exact road maps for detailed positioning.

ELECTRONIC CONTROL UNITS AND FUNCTIONS

ECUs receive commands to control vehicle functions such as acceleration, braking or steering.

DATA ON SITE

The massive data volume of a vehicle cannot be transmitted over the cellular network and processed. Local data processing is thus required.

HIGH-DEVELOPED DRIVER ASSISTANCE SYSTEM (ADAS)

The vehicle uses sensor data and external data (e.g. about traffic, weather, car-to-x) to determine the next driving manoeuvre optimally.

NEW INTERIOR DESIGN

The autonomous vehicle becomes the second living room or office with sophisticated infotainment. For this, special displays and interior equipment will be developed.

LIDAR

Generates a 360-degree image of the environment

CAMERAS

To determine the distance to other objects, cameras are also needed to detect traffic signs and signals as well as moving objects (e.g. bicycle riders and pedestrians) around the vehicle.

RADAR

Remote range sensors for measuring the distance between car and obstacles.

ULTRASOUND

Near field sensors – e.g. for parking

BLACKBOX

Record all vehicle manoeuvres, sensor data and ECU commands for the investigation of accidents and incidents.

ROAD USERS

With its sensors and car-to-x communication, the autonomous vehicle communicates directly with other road users – for trouble-free and accidentfree traffic.

ELECTRONIC PAYMENT OPTIONS

Payment options for infotainment services, tolls, parking fees or maintenance and repair, as well as refuelling or recharging the vehicle and other services must be created and controlled by the owner.

MOBILE RADIO AT LEAST 5G

Better networks with higher performance capability for the increasing use of infotainment and streaming services while driving as well as direct car-to-x communication.

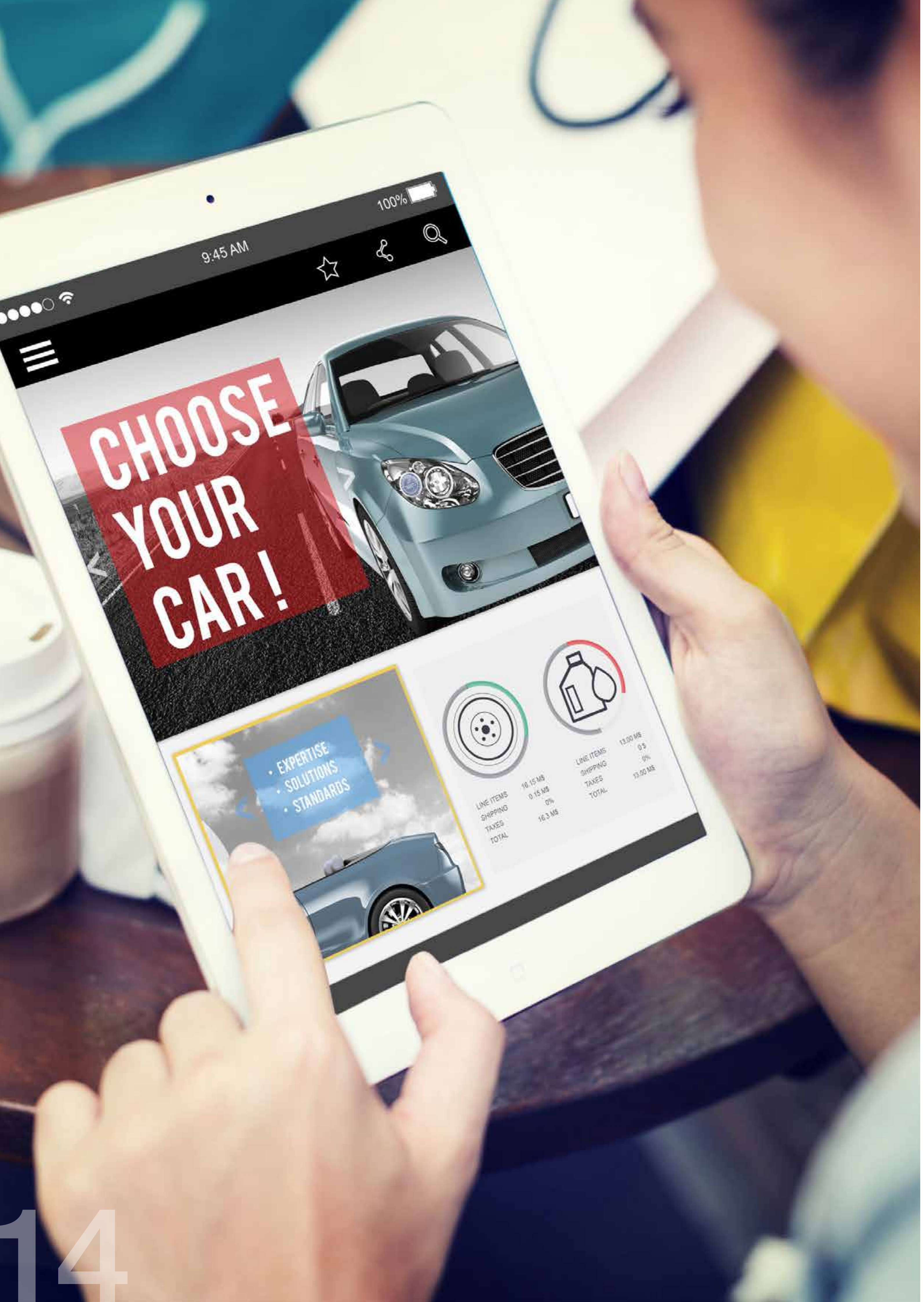
DEALER AND WORKSHOP

Autonomous vehicles know when maintenance measures are necessary: They arrange their own appointments with the workshop. Thus, the customer is no longer personally involved in the process, except in the payment processing.

PUBLIC INFRASTRUCTURE

Autonomous vehicles will be able to communicate directly with the public infrastructure, e.g. to book parking spaces in car parks or pay.

PARKING GARAGE



4. Scenarios for market penetration

In 2014, Elon Musk predicted that the technology for fully self-driving vehicles would be available in five to six years[1]. This would imply mass production starting in 2020. A study from 2015 assumes that consumers will have adopted the new automobile technology by 2030. By 2050, autonomous vehicles are even expected to become the primary means of transport[2].

On the other hand, Chris Dixon[3], a partner of investment firm Andreessen Horowitz in Silicon Valley, says the roads will be full of driverless vehicles in two to ten years – depending on which country you look at.

These contradictory statements demonstrate the difficulty in forecasting the proliferation of self-driving vehicles. In addition to market demand, many other factors influence market penetration. For example, one must take into account how many new vehicles are sold every year, what the vehicle inventory on the market is, and how many old vehicles are withdrawn from circulation (e.g. by scrapping or decommissioning) every year.

Moreover, previous data as well as predictions about trends in the automotive industry are necessary for a reliable forecast. Experts predict that car sales will stagnate – or even decline – in mature markets. In addition, business models such as car-sharing will continue to negatively affect the sales of new cars.

There are currently around 1.2 billion vehicles in stock worldwide; 73% of these (870 million vehicles) are in industrialised markets. Approximately one in every six people (one in three in developed markets) in the world owns a vehicle.

By 2020, when self-driving vehicles are expected to be commercially available, the number of autonomous vehicles sold will still be negligible, accounting for about one percent of all new cars sold. However, with increasing interest in the technology, further developments, and declining prices because of economies of scale, the proportion of autonomous vehicles among new sales will rapidly increase to 50 percent in the early 2040s and 100 percent later that decade. After that, the proportion of self-driving vehicles as part of the entire stock will surge.

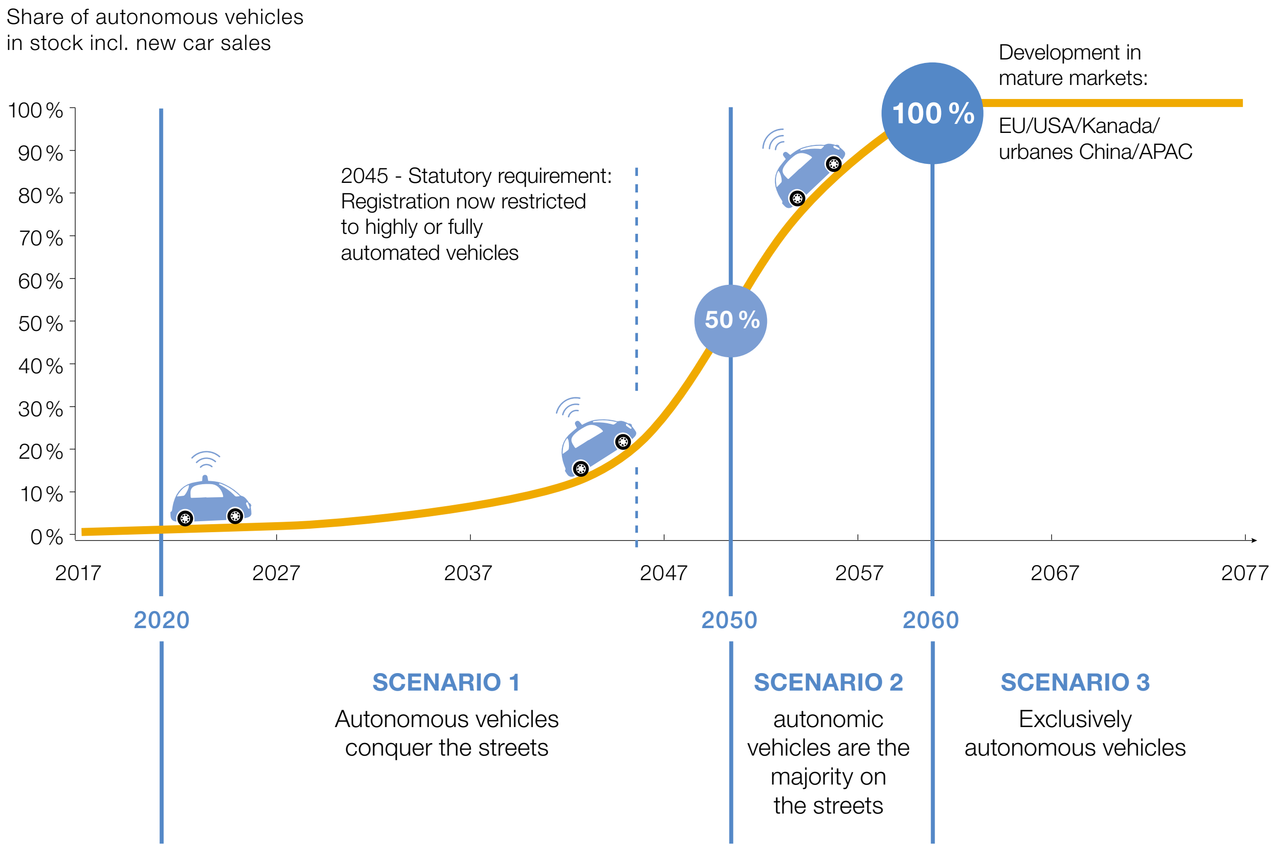
Autonomous technology will reduce human-related accidents and environmental damage. A legal requirement for the universal use of the technology (e.g. when introducing safety belts or airbags) also appears realistic with SDCs. In this way, a 100% market penetration is possible by 2060.

These assessments are based on the global assumption that newly registered vehicles must be autonomous (i.e. highly automated and only Levels 4 and 5) from the year 2045 onwards and that after a conversion phase of 15 years from 2060, only autonomous vehicles will be permitted on the roads. This means that a transition phase would be expected from 2045. Non-autonomous vehicles would have to yield the roads. Therefore, the number of decommissioned or scrapped vehicles will increase considerably. As a result, the number of new cars sold will also increase during this period.

In our scenario, as soon as statutory regulation requires the use of autonomous vehicles, the growth rate of new cars sold will initially increase. Its peak will be reached in the middle of the 15-year transitional period and then plateau again until all remaining non-autonomous vehicles must be replaced. A decline in the number of new cars sold is expected at the end of this period. According to our calculations, the market will be saturated with autonomous vehicles.

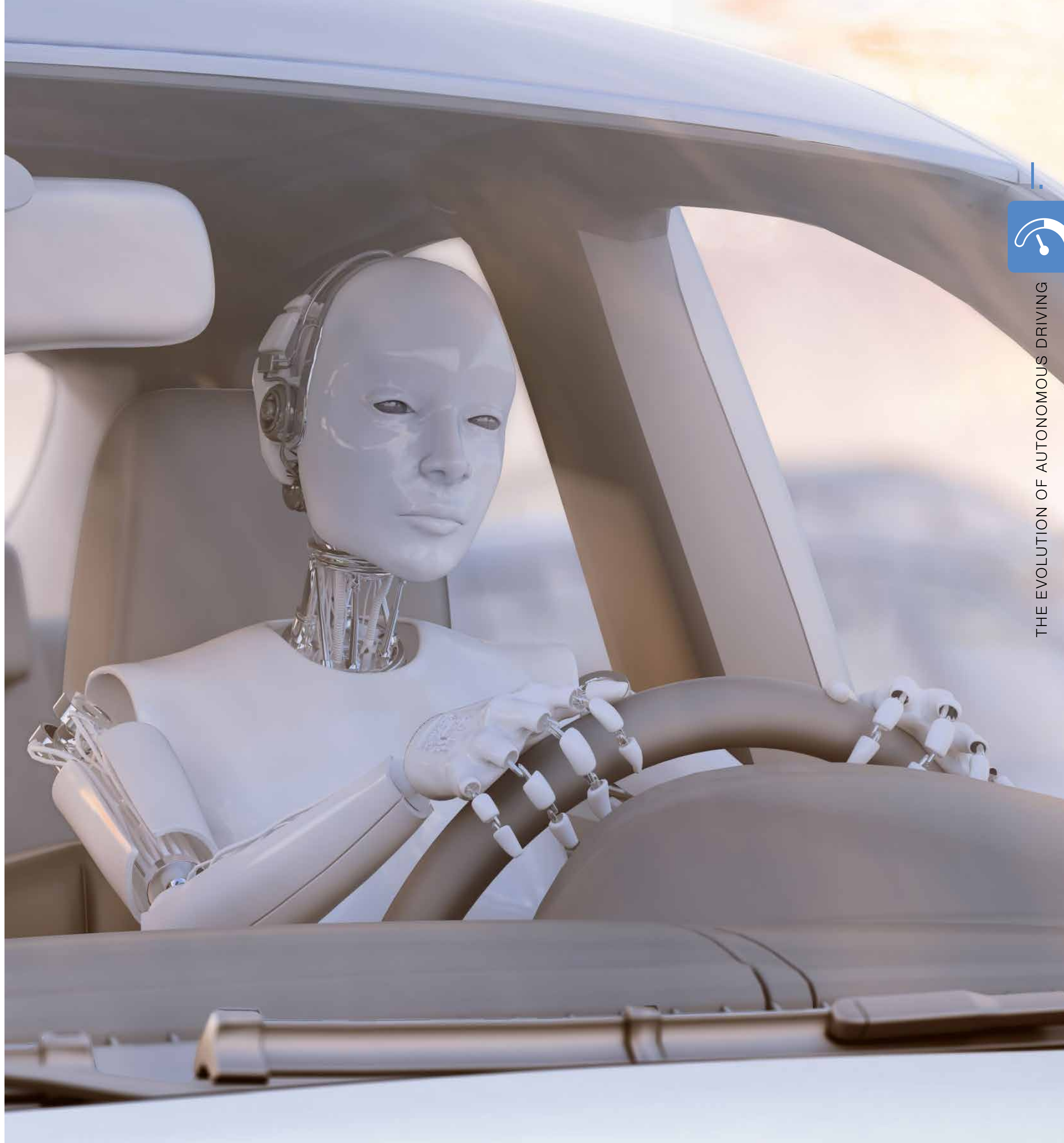
In this white paper, we would like to discuss the spread of autonomous driving in more detail using three scenarios. The classification of the scenarios presented is based on a series of assumptions and estimates as well as experiences and forecasts. These market development scenarios are not a comprehensive market analysis or forecast. Instead, we aim to formulate the potential development of the ecosystem around SDCs.

The three scenarios based on our own calculations



NOTE ON OUR THREE SCENARIOS

We will examine the three scenarios of autonomous driving as illustrated and the respective effects in different dimensions. The scenarios build on one another. We will therefore describe the innovations and/or changes in scenarios two and three, respectively.



"In 20 years' time, we will only be allowed to drive our own car with a special permit, because we are the greatest risk than humans. There will be autonomous driving. That'll be much more resource-efficient."

Angela Merkel, Chancellor of the Federal Republic of Germany

II. SCENARIO 1 (AROUND 2020):
Autonomous vehicles conquer the roads

With the continuous development of autonomous technology, the first, mass-produced self-driving cars will hit the roads and permanently change traffic, ecosystems, and our lives.

Highly-automated, mass-produced vehicles.
Scenario 1 illustrates the near future (around 2020), when autonomous vehicles will be sold commercially but still not widely used. These are highly-automated models (Level 4) in which the car drives independently but the driver must still be able to intervene in critical situations. Fully automated vehicles (Level 5) are only permitted for research purposes. At the beginning of the scenario, most vehicles will only be partially automated (Level 3). However, at the end of the scenario, highly automated vehicles will continue to prevail, and partially automated vehicles will slowly disappear from the roads.

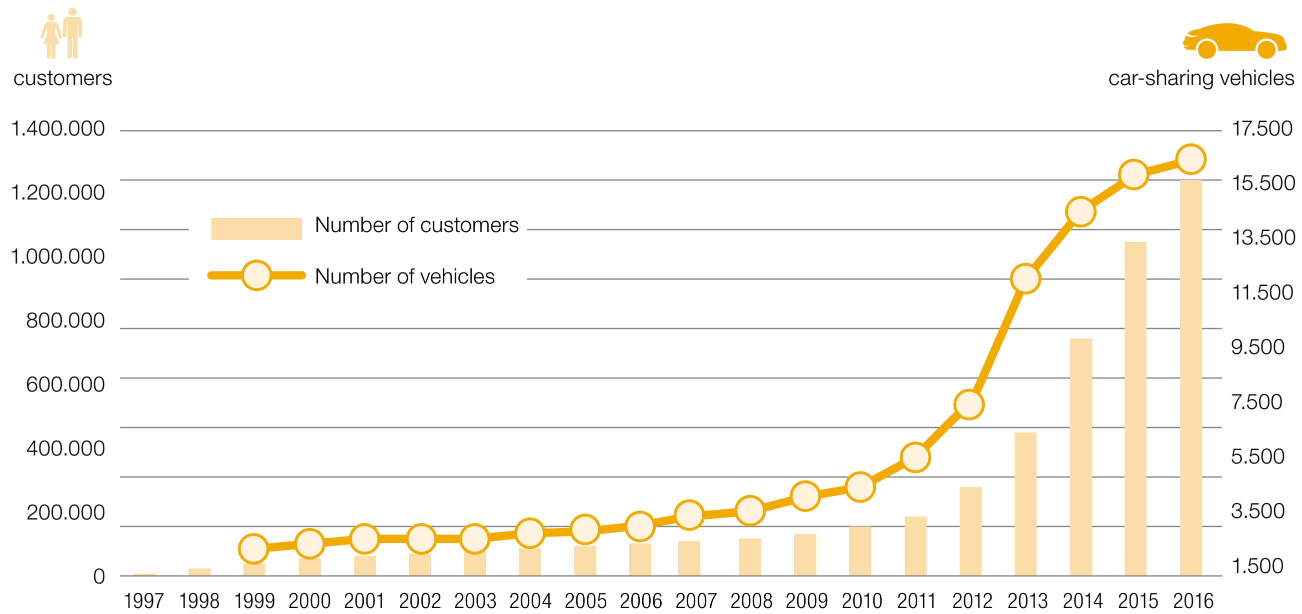
New business models.
The automotive industry is faced with a fundamental change in the orientation of its business models. Autonomous driving will increasingly focus on the end user and will be linked to the emergence of new services, which are not yet shown in the current automotive ecosystem. In the course of digital transformation, new players whose core business has not been primarily in the automotive industry will take the stage. Companies like Google, Uber, and Tencent as well as many start-ups will further accelerate the rethinking of established manufacturers and suppliers. Even today, a clear trend towards far-reaching cooperation and partnerships is emerging.

1. Sharing instead of owning

Private car ownership has been subject to constant change for years. For autonomous vehicles, the question arises as to who the potential buyers are. Will they be private owners, larger fleet operators, or even companies who operate their own car fleets?

Car-sharing is becoming increasingly popular.
Many users have recognised the advantages of car-sharing. Business models like car-sharing are becoming more appealing, especially for the younger generation. The number of car-sharing users in Germany has risen from around 300,000 in 2012 to more than 1.2 million in 2016.[4]

Development of the Car-Sharing Market in Germany[5]



It is apparent that fewer people will own cars in the future. It is difficult to say exactly what has led to this development: the generally changing relationship with mobility or the increasing comfort of autonomous vehicles, which also makes car sharing more comfortable.

However, the statements regarding car sharing are influenced by both determinants. Autonomous vehicles are initially more expensive. Car-sharing could therefore be more attractive in the early stages of development. If the price drops because of sharing, driving autonomous vehicles will become more affordable for a broader range of customers.

2. Autonomous vehicles in passenger and road traffic

Autonomous taxis.

Passenger traffic with buses, trains, and taxis could also change soon. In Germany, for example, there are over 53,000 registered taxis. That means that there are roughly as many or even more taxi drivers and other employees in this industry.[6] In the US, 233,000 people are employed as taxi drivers.[7] Salary-related costs are usually a significant portion in the price calculation of taxi companies. The switch to autonomous taxis would therefore be a logical step for the industry to be able to operate more economically. A pilot project is currently underway in Singapore. The city-state is already testing autonomous taxis, which travel in authorised urban areas.[8]

Savings in trucking.

Limits to hours driven in a day, lack of drivers, safety, and fuel costs are challenges faced by the trucking sector. Drivers of partially automated trucks (Level 3) do not always have to steer, thereby eliminating the problem of time constraint. This could lead to wage savings of up to six percent. However, a corresponding legal adaptation would be necessary here. In addition, the trucks can travel in a convoy (platooning) and save around five percent on fuel costs thanks to reduced aerodynamic drag.

Investments in autonomous vehicles is still high. Around 2020, it will still not be realistic to invest in autonomous vehicles for passenger transport or highly automated trucks. A driver will still be required, which means that there will be no savings in labour costs. We therefore assume that around 2020, only a few companies will be running pilot projects with autonomous fleets.[9]

3. Minimal changes in the passenger compartment

Marginal component change.

In the case of partially autonomous vehicles (Levels 3 and 4), the driver must be able to react at all times if necessary. Therefore, there will be no major changes in the interior of the vehicle. It may be possible to scale down components such as the steering wheel and pedals (acceleration, brake, and clutch) and offer them as an emergency function with minimalist design.

More exchange with co-passengers.

The way in which people sit or move inside the vehicle will only change moderately. For example, Johnson Control's ID15 innovation concept enables the front row of seats to be rotated about 18 percent. This will make interaction with people in the back seat more comfortable. However, it will still possible to assume control of the vehicle if necessary.

More infotainment.

Advanced infotainment systems are also conceivable – these would offer the possibility to go online, listen to music, or watch movies. Radical design changes will not yet be possible in this scenario. The interior will therefore not be a high priority for OEMs and suppliers.

4. New insurance issues

Insurance will still be necessary.
In Germany, there are about 2.5 million car accidents annually. Although only about 12 percent of the people involved are injured, a car accident can often be expensive.[10] In the event of an accident, average insurance costs between €740 (partial coverage) and €3,600 (liability) are payable by the insurance company. There are also additional costs for the car owner.[11] Although it is predicted that autonomous driving will reduce accidents, these will continue to occur as long as human drivers are involved. That is why insurance will still be necessary.

Black box like on an aeroplane.
The introduction of autonomous vehicles is a challenge for classic motor vehicle insurers. They must launch new products and clarify insurance issues. Driver are currently responsible for any damage they might cause. At the beginning of 2017, the German federal government introduced new laws for Level 3 and 4 vehicles. Using a compulsory black box (travel data recorder), analogous to that in the aircraft, it should be possible for authorities and insurance companies to distinguish whether an accident was caused by human error or a system defect. With this data, liability claims can be addressed to the driver or the car manufacturer.

5. Scenario 1 Overview

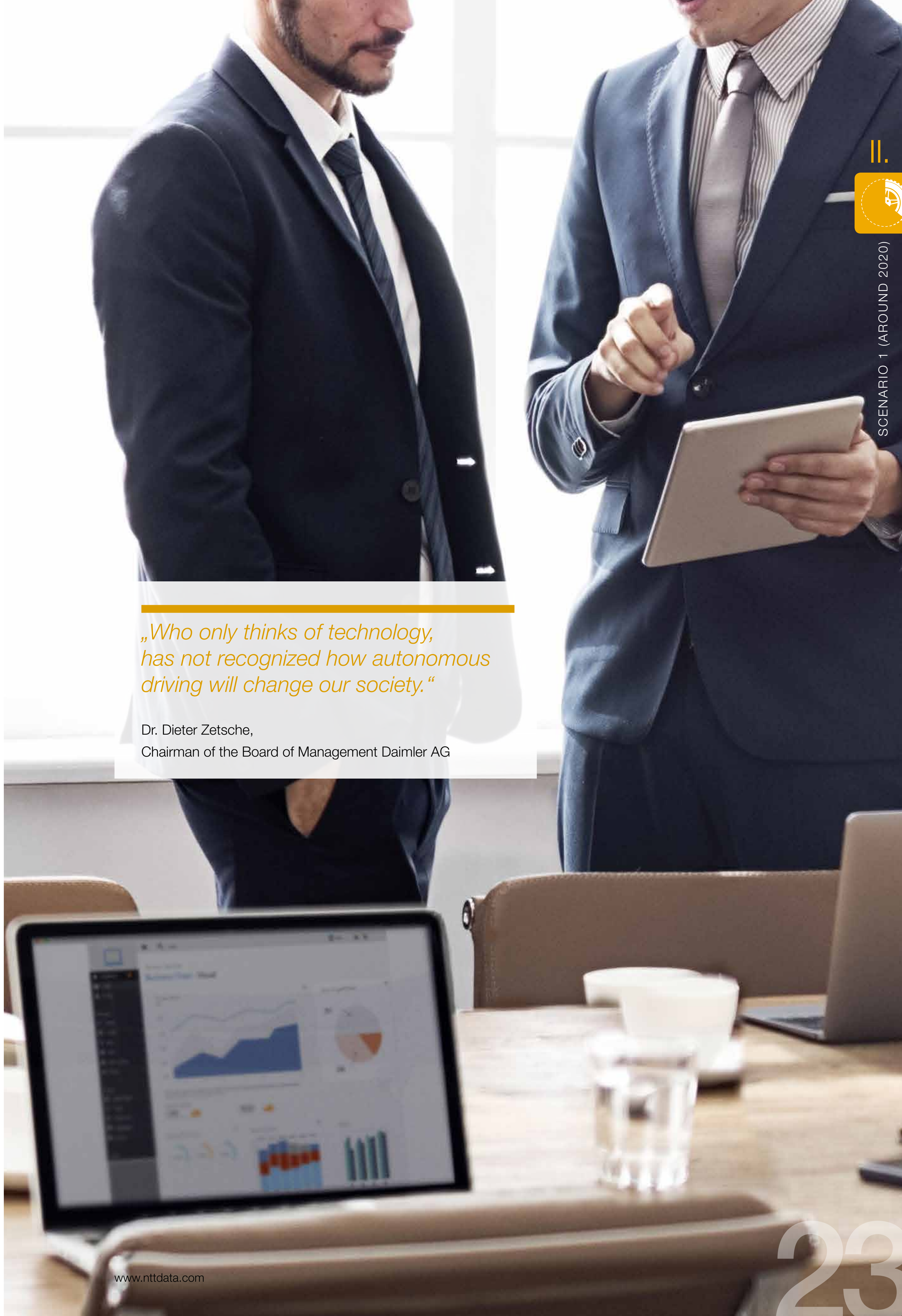
SCENARIO 1 AROUND 2020 – autonomous vehicles conquer the streets

Car-sharing
- Increasingly popular
- 450% increase in car-sharers in 2010-2016

Autonomous vehicles in passenger and road traffic
- Initial use in pilot projectsn
- In the case of trucks, fuel costs savings of up to 5% by driving in a convoy

Adaptations in the passenger cabin
- Moderate component change
- More communication with co-passengers
- More infotainment

Insurance
- Fewer accidents
- Insurance will still be necessary
- Black box necessary to record driving data



„Who only thinks of technology, has not recognized how autonomous driving will change our society.“

Dr. Dieter Zetsche,
Chairman of the Board of Management Daimler AG

III. SCENARIO 2 (AROUND 2050):

Mainly autonomous vehicles on the roads

With the growing number of autonomous vehicles on the roads, their influence on the ecosystem around the vehicle is also increasing – extensive changes to road traffic, the automotive industry and everyday life are expected.

Scenario 2 illustrates the long-term future around the year 2050, when autonomous vehicles will predominate on the roads. The increasing market penetration of completely autonomous vehicles of Level 5 will mark the beginning of a new era. Highly- and fully-automated vehicles (Levels 4 and 5) will characterise the streetscape.

1. The automotive industry is changing – new aftersales

Especially for mature automotive markets such as Germany or the US, aftersales is a mainstay for profit. With a current share of around 50% of the profit but only 23% of sales, the aftersales business continues to be indispensable for OEMs. How will aftersales change?

Fewer repairs, more maintenance.
The autonomous vehicle will significantly change the aftersales business and require a rethink. On one hand, there will be increased economic pressure on garages. Autonomous driving means fewer accidents are expected, which means fewer repairs will have to be carried out. On the other hand, the general use of the vehicles will be increased by car-sharing and autonomous taxis, so there will be shorter maintenance intervals. Another possible source of revenue could be the personalisation of car equipment, infotainment systems, and the interior. The passenger cabin will change significantly if the driver is no longer needed.

Companies will become the new aftersales customers.
The increasing use of car-sharing will also have a different influence on the aftersales sector. Traditionally, private car owners needing repair want to have their vehicle turned up or buy additional features. They are a large customer base for aftersales products and services. However, with the more frequent use of car-sharing and autonomous taxis, fleets will become increasingly more important.

The consumers of aftersales services will therefore primarily be customers with a large vehicle fleet. This can lead to discount agreements, which will offer far more favourable conditions than for private owners. This is similar to huge trading companies like Amazon, which have extensive contracts with shipping companies that include cheap bulk rates to offer free shipping.

2. New relationship between customer and OEM

More customer data.
The autonomous vehicle is turning into a computer that generates large amounts of customer data. The customer entrusts the data as well as its security to the OEM. The OEM in turn receives more information about its customer than ever before. The challenge for the OEM as well as potentially for the suppliers is to gain tangible benefits from the data (e.g. in the sense of predictive maintenance or cross-selling and up-selling).

In order to ensure that buyers of autonomous vehicles will not have to completely transfer their data to the OEM, they will – to a certain extent – be able to determine which data they would like to share and which services to use, much like a smartphone or tablet.

Stronger customer loyalty.
The need for regular software and security updates will intensify customer loyalty. In the interests of their own safety, customers have a certain degree of dependency on the OEM. Especially in the case of fully automated vehicles, people entrust their lives to the vehicle because they no longer have any influence over the actual driving. We therefore assume that customers will be more likely to bring their vehicles to the OEM garage than to an independent garage. We also assume that the OEM knows the technology best because it will have developed it. It will most likely be able to provide the best quality services and original spare parts.[12]

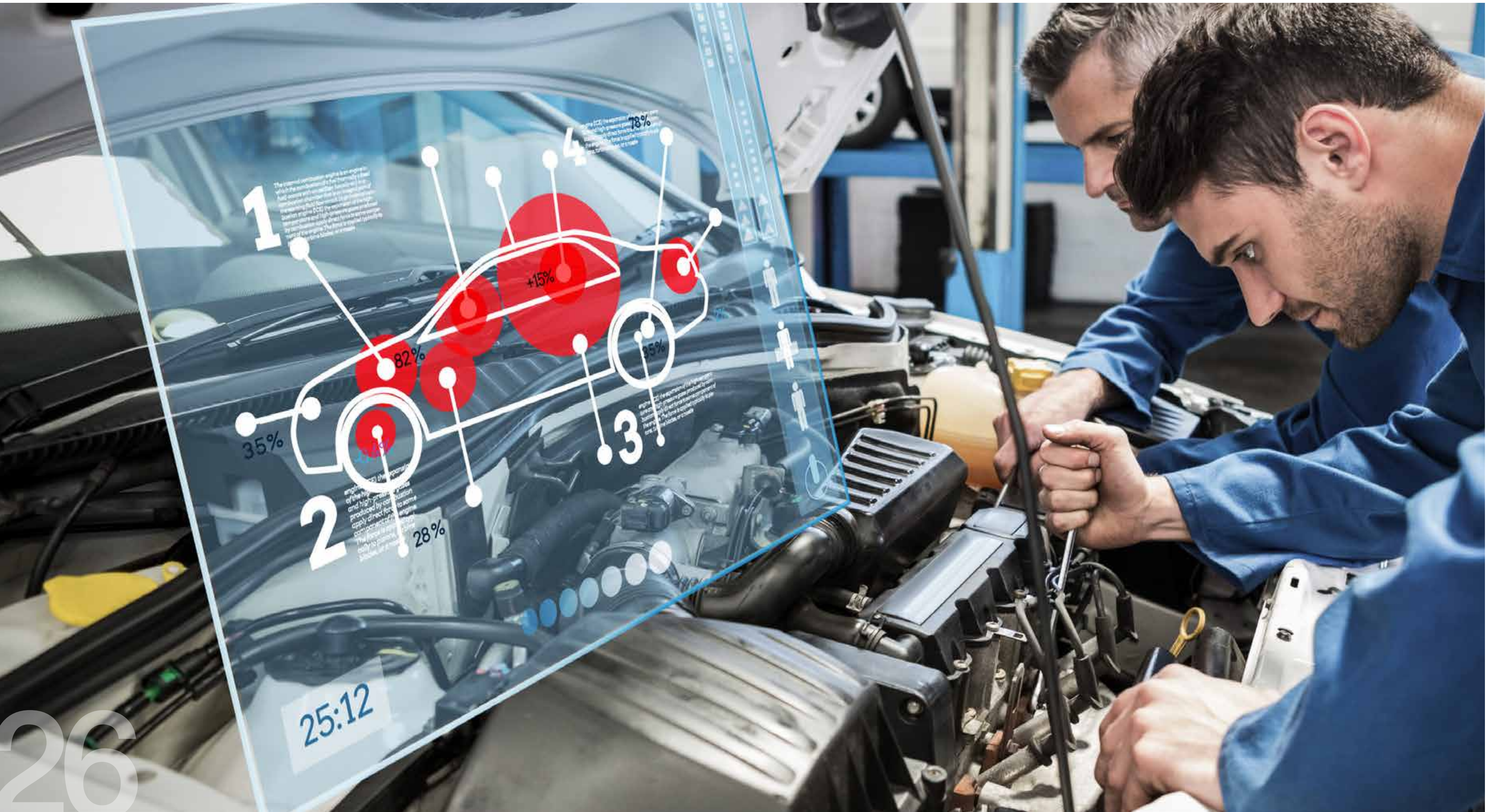
Personal contact?
With the car – not with the driver!
Even if the technological reliance on the OEM increases, the personal contact between the employees of the OEM garage and the customers will decrease. This is simply because fully automated vehicles can register faulty parts, damage, and maintenance requirements and manage themselves independently. The vehicles can order spare parts, arrange an appointment with the garage, and even drive there themselves. The customer is thus no longer personally involved in the transaction except for payment processing.

3. Mechanics will become IT specialists

Autonomous vehicles will become rolling computers, conventional vehicles will no longer be available, and steering wheel manufacturers will no longer have a market. This means that OEMs and suppliers will have to rethink their components and products. Furthermore, new types of employees will be needed.

Employees with knowledge of IT will be in demand.
Increasingly more software and increasingly fewer mechanical components in the vehicle will lead to profound changes in the automotive world. Classical engineers with a specialisation in mechanical or electrical engineering will no longer be responsible for vehicle development. OEMs and suppliers will increasingly be seeking employees with a comprehensive understanding of IT, vehicle IT architectures, and software development.

More IT than sheet metal.
With increasingly complex vehicles, which will be more of a software rather than a hardware product, the tasks of car mechanics or mechatronics engineers will also change. IT knowledge and hardware knowledge on all technical components such as ADAS, radar, lidar, and navigation as well as infotainment and connectivity systems will be crucial. It is therefore expected that the mechanic's work will soon be similar to that of a technology specialist.



4. Car-sharing will keep growing

With Level 5 car-sharing vehicles, car-sharing will be a bit more convenient. Drivers will no longer have to look for a vehicle that might happen to be parked in the vicinity; they can simply call a vehicle and drive to their chosen destination.

New business models, platforms, and concepts.
Because Level 4 and 5 autonomous vehicles will initially be cost-prohibitive, car-sharing will be a viable alternative and is therefore likely to increase in importance for economic reasons. It is conceivable that new business models as well as new types of platforms and concepts will be developed as part of car-sharing. If vehicles longer require drivers, private car owners will also be able to register their vehicles on sharing platforms and make them available for when they do not need them themselves.

Premium car-sharing.
It will also be possible to offer exclusive car-sharing services for luxury-class vehicles in which only premium customers will be able to participate. This model will work like certain dating platforms to which only academics or wealthy people can sign up. Access will be controlled by a high registration fee or high monthly contributions or rental costs. Such a business model could increase the willingness of owners of expensive vehicles to make their cars available on such a platform.

In addition to these business models, other lower-priced models in which more people can share a car-sharing vehicle and obtain a better price are conceivable. These can best be compared with car-pooling services that are currently on the market.

5. Will insurance companies be superfluous?

In Germany, motor vehicle insurance currently accounts for 13% of the total market and is thus an important segment of the industry. With insurance premiums of around $228 billion annually, the auto insurance sector is also crucial in the US. It is therefore in the interest of insurance companies to develop an appropriate tariff models for autonomous vehicles.

New responsibilities.

Until fully automated autonomous vehicles will reach the road, suitable contracts will have to be developed and important questions will have to be addressed. If the driver cannot be held responsible for accidents caused by computers, who will be? Will the vehicle manufacturer be liable for such accidents? Will the future driver still be the policyholder, or will responsibility be transferred to vehicle manufacturers? What will happen if the driver is late in updating the software for his vehicle and causes an accident? What will happen if a general software error causes an accident or the failure of an entire series? Another important question is: who will be liable for damage caused by hackers exploiting a security vulnerability in the system?

Significantly fewer accidents.

In this scenario, we assume that the damage caused by traffic accidents can be reduced by 50 to 70 percent. Conventional vehicles will be on the road together with autonomous cars and thus also be involved in accidents with one another. Based on the assumption of highly developed autonomous technology between the years 2050 and 2060, we assume that accidents will largely be caused by conventional vehicles – or rather their owners. Through the use of black boxes, it must be possible for the authorities and insurance companies to prove or rule out a failure of the autonomous technology.

New insurance models and contributions.

With increasing statistical experience in the parallel operation, insurers will be able to develop appropriate contribution models. Even assuming that OEMs will be largely liable for damage to fully automated vehicles, they will transfer the corresponding costs to the vehicle purchase price, leasing rates, or car-sharing fees or cascade liability claims along their upstream supply chain.

6. New forms of fee collection and invoicing

Payment process will also change because of two autonomous vehicles. If the vehicle parks, recharges itself, or drives to the garage without the owner, invoices will need to be paid without the cardholder being on site.

The vehicle pays for itself – possibility 1.

In order for the vehicle to be able to carry out the corresponding processes independently, it must know or have access to payment data. One possibility would be to store the payment information directly in the vehicle. In this way, no internet connection would be necessary, and M2M communication would suffice. The machine requesting payment (e.g. a car park barrier or a charging system) would send the payment request to the vehicle, the vehicle would transmit the payment information and authorises the amount, and the payment would be made via the connection of the machine to the card server.

The vehicle pays for itself – possibility 2.

Another possibility would be to store the payment data in the connected car backend. This option would allow vehicle owners to make the payments (e.g. vehicle maintenance) so that necessary payments can be made via the backend.

Payment via smartphone.

With both options, the cardholder should be able to accept or reject payments via the card server's push services on the smartphone. Alternatively, there could be different default payment options. The cardholder will thus be able to personally configure which types of products or services up to what amount may be delegated autonomously (delegated payment) without the authorisation of the owner. For example, repairs worth more than €1,000 would have to be approved by the owner, whereas battery charging would always be possible without approval.

The processing of payments without the actual card but only via the payment information stored on the smartphone is currently available from Apple Pay and Android Pay. With the right technology, the autonomous vehicle will be capable of offering the same payment services as smartphones. A precondition would be that the companies involved support the applied payment system.

7. What happens to driving licences and driving instructors?

Every year, around 1.15 million Germans receive a driving licence. At an average cost of €1,800 for a driving licence, this amounts to around €2 billion a year. Especially in Germany, this is not only expensive but also time-consuming. Driving instructors show us how to drive and convey all the important road traffic rules. But will the job of a driving instructor not be endangered when autonomous vehicles become more of a reality?

In Scenario 2, which uses both highly-automated and fully-automated vehicles, the question arises as to whether we even need driving lessons and driving licenses for the use of autonomous vehicles. The answer seems clear for highly-automated vehicles. As long as drivers need to be able to interven in critical situations, driving skills and a thorough knowledge of the road regulations are still required. A driving licence is thus indispensable. However, it will be necessary to rethink the content of driving school teaching. As the technology becomes increasingly more complicated, it will become increasingly more important for the renewing driver to learn how to deal with it.

"I am convinced that my children will no longer need a driving licence"[13]

Johann Jungwirth, Chief Digital Officer Volkswagen AG

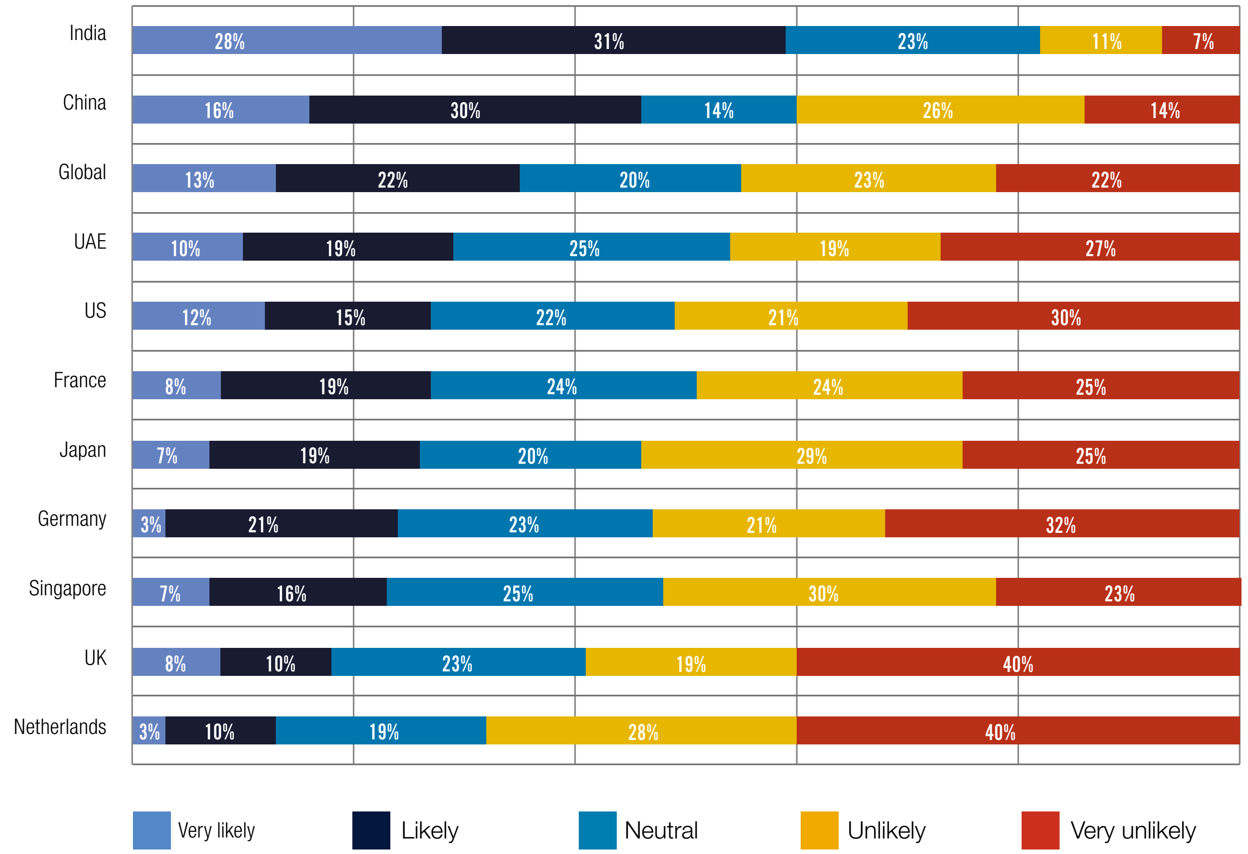
When it comes to vehicles in which the passenger is only a passenger, the answer appears less clear.

Will we still need a driving license for autonomous vehicles? If so, what will the content look like? What will happen to the more than 45,000 registered driving instructors and the 17,000 driving schools in Germany alone if their work becomes superfluous? Politics and society will have to find answers to these questions.

Will it also be necessary to clarify the minimum age for the use of autonomous vehicles? What if a ten-year-old would like to play football with friends? In principle, he or she would only contact the autonomous vehicles of his parents or a car-sharing, which will pick him or her up and take him or her to the football field. Even if this was possible, would parents and society want their children to travel like this by themselves?

The World Economic Forum asked parents from several countries:[14]

How likely would you be to let your children ride alone in a fully self-driving car?



The survey shows that a lot of parents do not want their children to drive alone in autonomous vehicles. Only in India and China would a large number of people be willing to let their children use autonomous vehicles alone. Especially in the western industrialized nations, the Netherlands, and the UK, people would be reluctant to let their children us autonomous vehicles. However, in view of the advancement of technology and means of transport, this is a social issue that should be considered more intensively.

8. The vehicle interior as a living or office space

The steering wheel, gas pedal, clutch, and brake will become things of the past.

In Scenario 1, we described that changes to the passenger compartment will be moderate. The driver of a highly-automated vehicle will have to be able to intervene at any time whilst driving. This will change with fully-automated, driverless vehicles: No driver means no responsibility or even option to take control of the vehicle. The steering wheel, gas pedal, brake, and clutch will no longer be part of the car. The way we drive will change dramatically.

Completely different interior design.

Possible modifications to the interior include changes to the arrangement of the seats so that the passengers will be able to face each other and thus converse more comfortably. Furthermore, it will also be possible to work at a table or simply enjoy the benefits of the infotainment system whilst on the road. By this time, all vehicles will be equipped with an ultra-fast and highly stable internet connection of the tenth to twelfth generation.

Rolling Office.

Current partnerships are already demonstrating the intensive efforts to integrate the familiar office environment into vehicles. For example, Microsoft and Volvo are working to establish Skype for the use of telephone or online conferencing into vehicles. This can be used to make the typically idle time in the car more productive.

Flexible displays.

Vehicles that will be increasingly used as infotainment platforms or mobile offices will require displays of various types and sizes to display content to the passengers. The interior of an autonomous vehicle will therefore be characterised by flexible displays. This will allow the advertising industry the opportunity to use advertising space (e.g. for location-dependent services) in the vehicle. The intensity of advertising will depend on whether it is a private car, a vehicle from a car-sharing fleet, or an autonomous taxi.

Displays and infotainment are only a small part of the possible changes to the interior of vehicles. The functions and interior design of autonomous vehicles leave plenty of room for new business ideas and innovations.

9. Local passenger transportation will be more flexible

In Germany, an average of 30 million people currently uses public transport every day. If fully automated vehicles are introduced to the market, some of the benefits of public passenger transport will be transferred to these vehicles. When looking at the future of public transport, however, one must clearly distinguish between urban, regional, and long-distance means of transport.

More autonomous taxis

In the highly-automated vehicles described in Scenario 1, it would not be economical to switch from conventional taxis to SDCs. They will still require a driver to ensure the safety of the passengers.

With autonomous vehicles of Level 5, economics will necessitate the construction of autonomous taxi fleets. Considerable labour costs can be saved with autonomous taxis. As a result, the new vehicles will pay for themselves more quickly. As a reminder, taxi drivers in the US earn $23,000 per year on average.

The completely autonomous Level 5 vehicles will also be interesting for Uber and Lyft. They will essentially be able to do their own work whilst the owners work or sleep.

Autonomous public transport in cities

Especially in the cities, road capacity is completely exhausted even though most of the vehicles are parked most of the time. If all people currently using use public transport switched to autonomous vehicles, the roads would be even more overloaded.

Advantages of autonomous buses and trains.
The use of autonomous technologies for bus fleets, trains or subways will be able to save costs. As a result, even neighbourhoods with less frequent connections will be able to be reached conveniently. This would enable innovative models for public transport in inner cities. If, for example, buses did not follow a predetermined schedule but rather travelled where the current demand was, passengers could reach their destinations faster and more convenient. The sharing of vehicles or minibuses by several people could also be a promising business model for autonomous, mobile fleets.

In this scenario, we are still referring to highly automated and fully automated vehicles. The following approaches for public passenger transport, among others, would therefore be conceivable:

- Extension of bus fleets to autonomous vehicles so that even less frequented districts would be more frequently accessed and thus more easily accessible
- Step-by-step transition of public transport to autonomous vehicles in order to save labour costs

These developments seem plausible for large cities. If the local and medium-range traffic between towns and villages is considered, the situation is different.

Autonomous public transport in rural areas

Buses and trains running between small towns and villages are mostly used by people who do not have a driving licence or own a car. It is usually more convenient to drive with your own vehicle. However, local public transport is still necessary in rural areas so that people without a vehicle or driving license can get around.

The bus does run only twice a day.
The main disadvantage of this transport system is the low frequency at which most destinations are being reached – especially in the late afternoon and at night. Autonomous driving could lead to a noticeable improvement because it will be possible to adapt the frequency of trips to the actual customer requirements. Labour costs would also decrease because of the reduced demand for drivers.

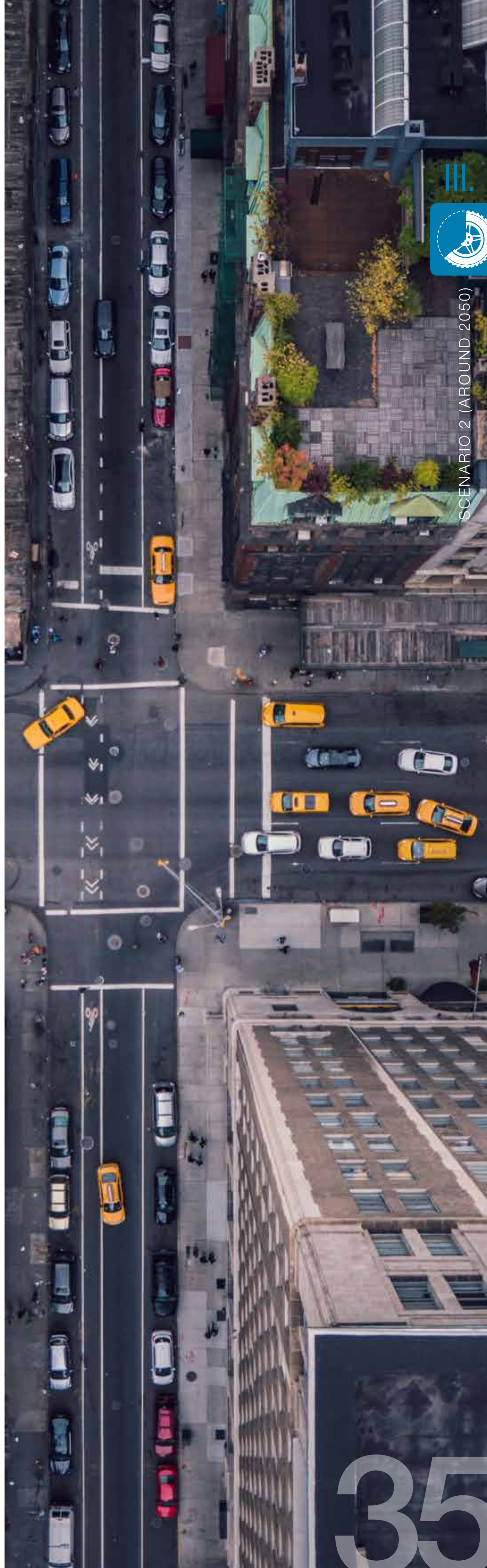
Car-sharing for greater mobility.
Level 5 autonomous driving cars will therefore be able to provide more mobility to people living in the countryside. An increase in the car-sharing supply in rural areas will also expand flexible and convenient door-to-door transportation.

Autonomous public long-distance transport: autonomous buses and trains compete for long-haul travel

In Scenario 2, we assume that there will be a market for both rail and road long-distance transport and that both modes of transport will operate alongside each another.

It is difficult to predict which means of transport – rail or road – will be more successful in the future. Even in times of autonomous cars, trains have many advantages, especially as the network for high-speed connections is further developed. However, because of the greater flexibility and the more convenient door-to-door transport, autonomous buses or car-sharing fleets also stand a good chance.

Autonomous technology will certainly lead to a change in our public transport system. Competition between rail and road systems will also continue to intensify, which will benefit passengers in the form of improved services.



> *“I think it’s pretty big, I’m on the record as saying we are in the midst of seeing more change in the next five years than we’ve seen in the last 50 years. I haven’t thought about it as the most significant, but I would say it’s right up there when you look at how dramatically people will move because there have been a lot of evolutionary improvements.”*
>
> Mary T. Barra, Chief Executive Officer und Chairman, General Motors Company

10. How will traffic, cities and life change?

By 2050, Level 3 and 4 autonomous vehicles will be ubiquitous. Our traffic, our cities, and our lives will thus also undergo profound changes.

Never again look for parking.

The example of a networked vehicle shows how technology can change the way we move and use our vehicles. For example, drivers spend an average of 100 days of their lives looking for a parking space. The use of parking assist technology with the help of social real-time data is a first step towards effective parking, especially in metropolitan areas. Once most vehicles are able to park themselves, the use of parking spaces will become more efficient. In particular, fully-automated vehicles will be able to use parking space outside of the crowded city centres. They will drive there independently after the passengers have gotten out. Car-sharing vehicles will be used more frequently and thus left parked less often. As a result, more space will be opened up in urban centres, and more green spaces and recreation areas can be created.

Never again be stuck in a traffic jam.

Thanks to extensive maps and navigation data as well as the communication between vehicles on the road, it will be possible to organise traffic more smoothly, thereby considerably reducing traffic jams. To this end, manufacturers are working on introducing improved satellite-based navigation systems.

Never again stop at traffic lights.

As the Internet of Things (IoT) evolves, vehicles can communicate directly with components of the traffic management system (e.g. traffic lights or parking garage barriers). This car-to-X communication will increase the efficiency of the entire ecosystem of the autonomous vehicle.

More safety for cyclists and pedestrians.

With increasing numbers of autonomous vehicles, the number of accidents caused by human error will be reduced. This will make cities safer, especially for pedestrians and cyclists. Good indicators for this development are statistics on Tesla vehicles in the US. According to a report from the National Highway Traffic Safety Administration (NHTSA), the accident figures for Tesla vehicles have fallen by nearly 40 percent since the self-driving technology was installed in their first version of the autopilot.

Improved quality of life.

Overall, the technology of autonomous vehicles, especially in conjunction with true zero emission electromobility, will significantly increase the quality of life. There will also be corresponding offers on local racetracks for anyone who wants to drive his or her 1976 Porsche 911.

11. An overview of the most important facts

SCENARIO 2 – predominantly autonomous vehicles

Car-sharing
- Continues to grow
- New business models, platforms, and concepts

Change in aftersales
- Fewer repairs and more maintenance
- Companies will be the new aftersales customers

New relationship between customer and OEM
- More customer data for the OEM
- Stronger customer loyalty
- Closer contact with the car – not with the driver

Mechanics to become IT specialists
- Employees with knowledge of IT will be in demand

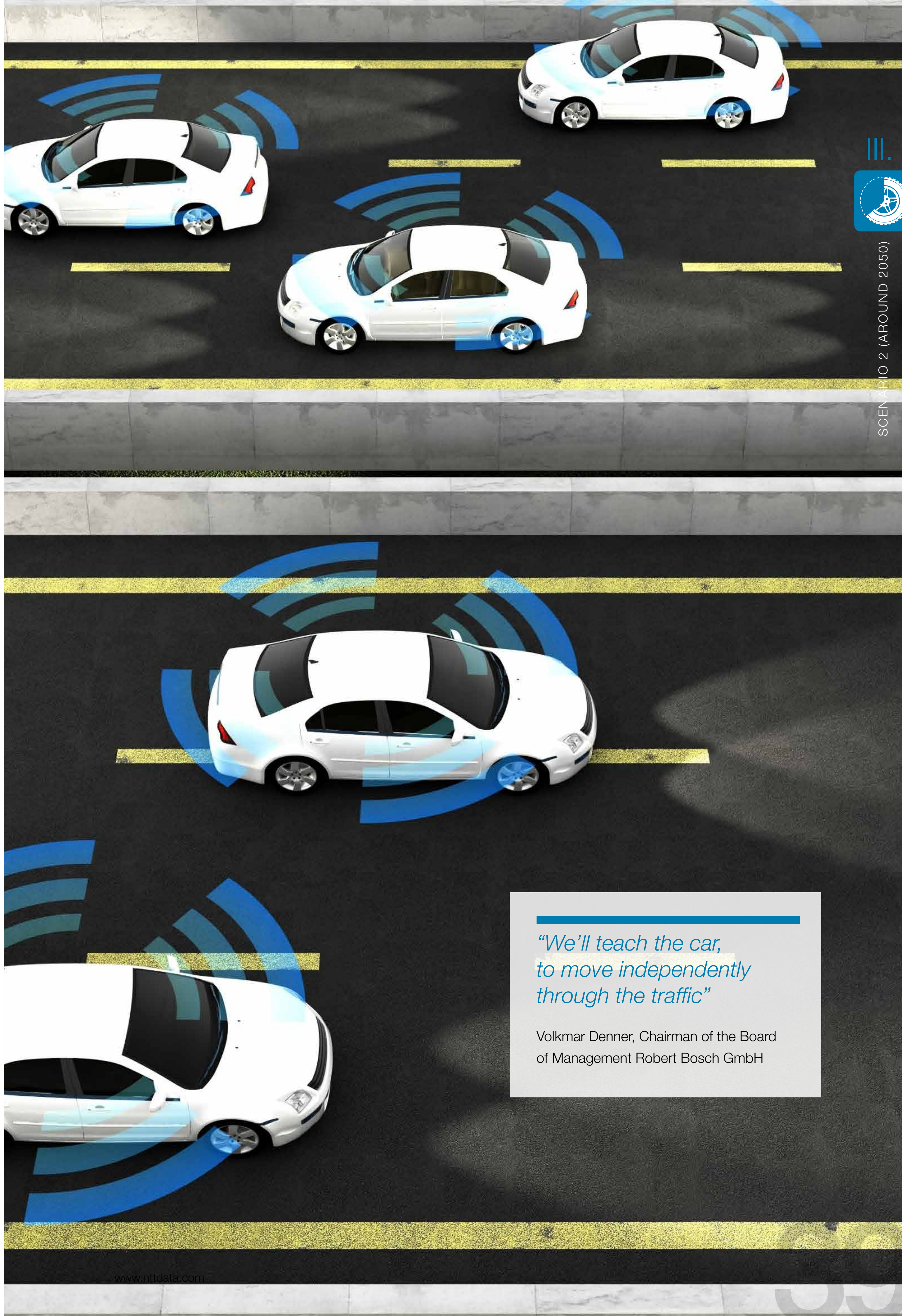
Insurance
- Significantly fewer accidents
- New responsibilities
- New insurance models and contributions

New forms of fee collection and invoicing
- The vehicle itself pays
- Payment via smartphone

The vehicle interior as living or office space
- Completely different interior design
- Vehicle as rolling office or living room

Local passenger transportation will be more flexible
- More autonomous taxis
- Autonomous public transport in cities and in the countryside, creates flexibility

Other changes for traffic, cities and life
- Never again be stuck in a traffic jam
- Never again look for parking
- Never again stop at traffic lights
- More safety for cyclists and pedestrians
- Improved quality of life



"We'll teach the car, to move independently through the traffic"

Volkmar Denner, Chairman of the Board of Management Robert Bosch GmbH

IV. SCENARIO 3 (AROUND 2060): a world with only fully-automated vehicles

Starting from 2060, fully-automated vehicles will be the only type of vehicle on the road. The technology that makes completely autonomous vehicles possible will have been completely developed in Scenario 2. Improvements and new components will continue to be an issue. The self-learning intelligence (machine learning) will be highly developed and be able to draw on a broad range of experience of millions of vehicles and billions of kilometres travelled. With fully-automated vehicles, there will be major changes in road traffic with fully-automatic vehicles. The ecosystem around the vehicle will have completely adapted to the new conditions. Our mobility will no longer be as the current generation knows it.

1. Car-sharing as a model for the future

Use cars instead of buying cars.
The issue of car ownership will have changed significantly with the introduction of autonomous technology – changes are already in motion today. The current, younger generation and big cities are increasingly turning away from buying assets like cars. They prefer to pay for their use (pay per use). The current automotive industry is still focused on business models with property. However, with the changed attitude of millennials, this model faces great challenges.[15]

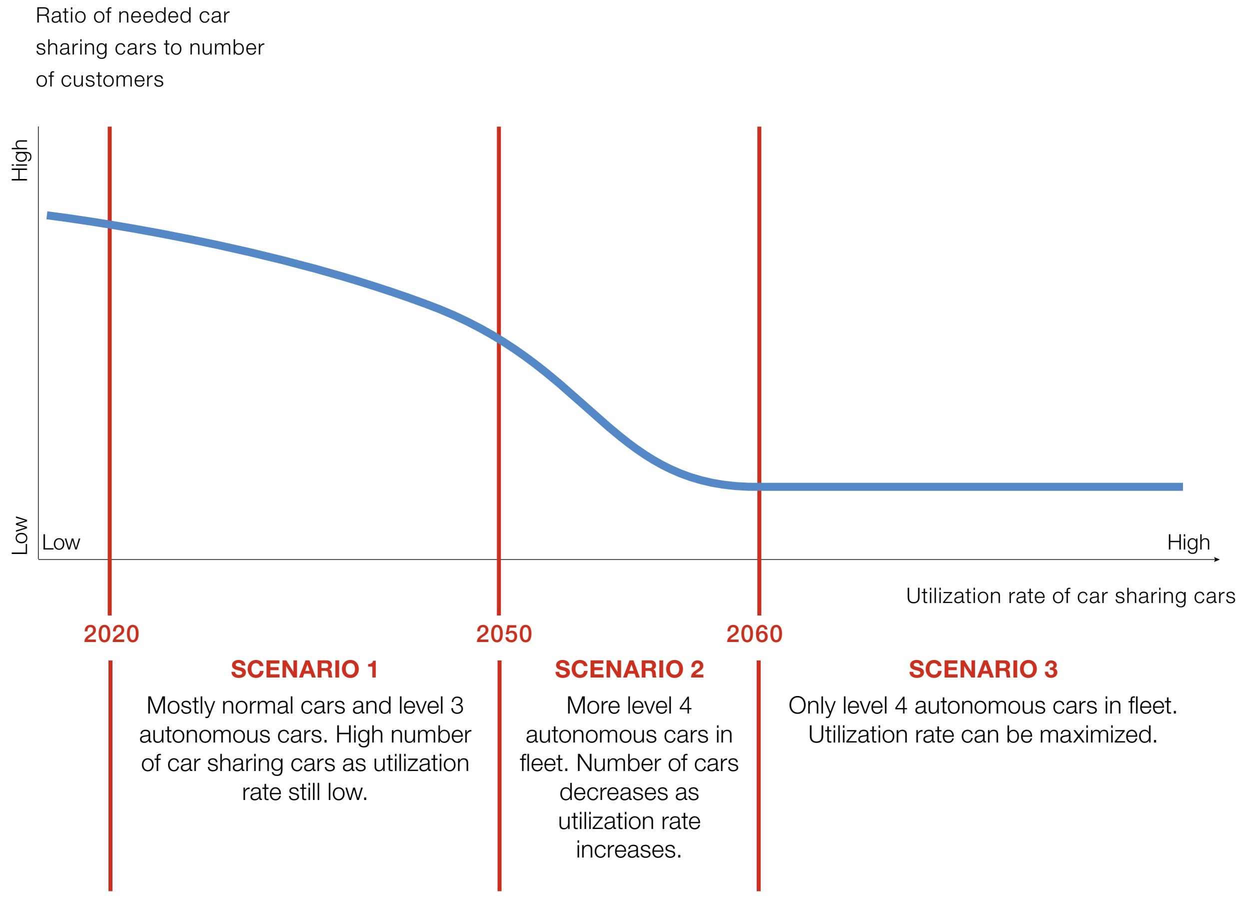
The car comes to the customer.
Against this background, car-sharing will be a promising business model. If there are only autonomous vehicles on the roads, car-sharing will develop further. Nowadays, the users of a car-sharing company's vehicle must still actively search nearby. It will be possible to easily call fully autonomous vehicles to the desired location to pick up the users – door-to-door car-sharing will thus be possible.

Car-sharing will become business as usual.
This will increase the effectiveness of the service, and the utilisation of the vehicles can be maximised. As a result of the increased convenience for the user of car sharing, the clientele will expand, car-sharing companies will maintain a larger stock of vehicles. We assume that the ratio of vehicles per customer will be lower because the available vehicles will be better utilised. As a result, it will be possible to offer the service at a more affordable rate. This will further increase the attractiveness of car-sharing.

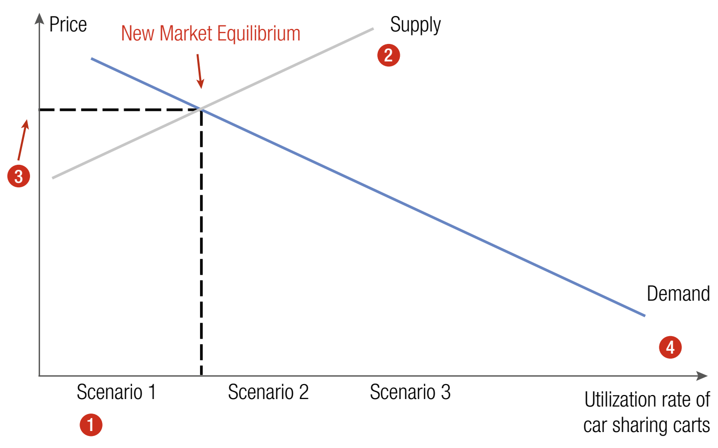
WHAT FACTORS WILL INFLUENCE VEHICLE UTILISATION?

- On-the-spot and ubiquitous availability (door-to-door service)
- Different vehicle types for different applications
- Simple billing models
- Car no longer a status symbol
- Alienation of man and car (no more driver – only passenger)

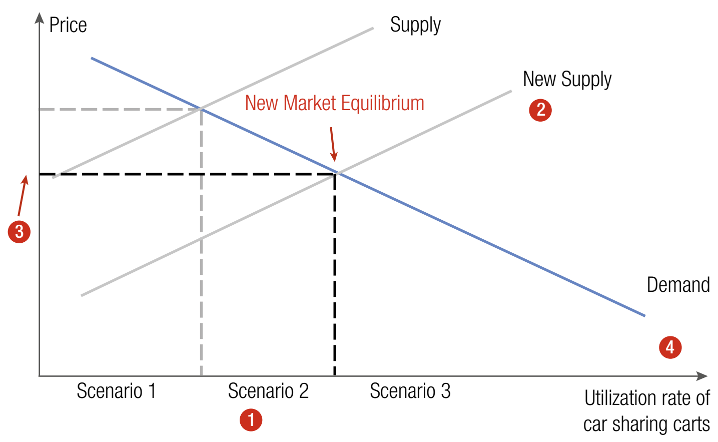
Changed ratio of the number of vehicles required per customer because of increasing usage figures



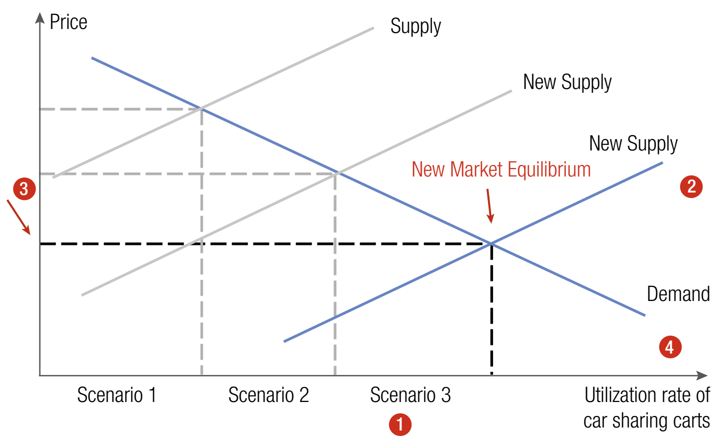
Supply and demand model



1. In S1 utilization rate of car sharing cars is low because cars level 2-3 have to be allocated all over the cities waiting for customers close by
2. Supply of service is low because cars are unused for a lot of time waiting for customers
3. Therefore, price at market equilibrium is high
4. Demand for car sharing services at that price is low



1. In S2 utilization rate of car sharing cars increases because cars level 4 are entering the fleet and they don't have to be allocated all over the cities but can drive wherever needed by themselves
2. Supply of service increases
3. Price at new market equilibrium decreases
4. Demand for car sharing services at cheaper price increases



1. In S2 utilization rate of car sharing cars increases further with only level 4 cars being used in autonomous car fleets flexible at all places at every time
2. Supply of service increases further
3. Price decreases further due to further optimized utilization rate
4. Demand for car sharing services at cheaper price increases further

2. Challenges for car manufacturers

Strongly declining new car sales.
Although the future development is positive for the car-sharing industry and is attracting increasingly more vendors, it could have a disastrous effect on car makers if there is no adequate transformation. The largely property-based business model of the automotive industry will no longer be applied in the zeitgeist of the future. Experts already predict a declining growth rate in new car sales. Cars are currently used only five percent of the time. The remaining 95 percent of the time – which seems perfectly normal to us today – they are parked and unused. Once we have reached Level 5 of autonomous vehicles, we can expect a utilisation rate of more than 60 percent. The resulting 12-fold increase in capacity utilisation will have a sustained negative effect on future passenger car sales.

No more brand loyalty.
In addition, brand loyalty will become less important in the acquisition of a new autonomous vehicle. When using autonomous taxi or car-sharing services, the customer will no longer attach great importance to the brand. Other criteria such as punctuality, reliability, price, or cleanliness will be the focus.

3. Car-sharing's fresh chance

From automobile manufacturer to car-sharing provider.
OEMs have the opportunity to offer car-sharing or invest in the infrastructure of car-sharing services. For example, BMW and Mercedes recognised this trend a few years ago and started to build their own car-sharing business model with ‚DriveNow' and ‚Car2Go', respectively. General Motors recently invested around $500 million in the car-sharing start-up Lyft. Many of the premium providers are already well positioned here, whilst the mass suppliers are playing catch up. The OEMs can also extend their car-sharing business through their own autonomous fleets. For example, they can advertise their own vehicles for customers of their company-internal car-sharing services.

The question is whether the imminent loss of sales resulting from a declining global vehicle market in times of autonomous driving can be adequately compensated by car-sharing or other new business segments (e.g. connectivity, advertising, extended infotainment services, or gamification).

EXAMPLE SCENARIO 2060 – TURNOVER LOSS OF €1.2 TRILLION

- Average utilisation of passenger cars in 2017 = 5% and 2060 = 60 %, which corresponds to a 12-fold increase
- Assuming a 40% increase in global mileage per year, this means that only 11.7% more vehicles than in 2017 will be needed in 2060 (basis: 100%): 140% × (100%/12) = 11.7%
- The top 10 automotive OEMs generated sales of around €1.4 trillion worldwide in 2016.
- In 2060, the comparable market (conservative without inflation) would only amount to €163.8 billion (11.7%).
- The OEMs, including the entire supply chain, would therefore have to compensate for a loss in sales of approximately €1.2 trillion.

4. The aftersales business of the future

It is questionable what opportunities the future aftersales business will offer. The following factors will influence the market:

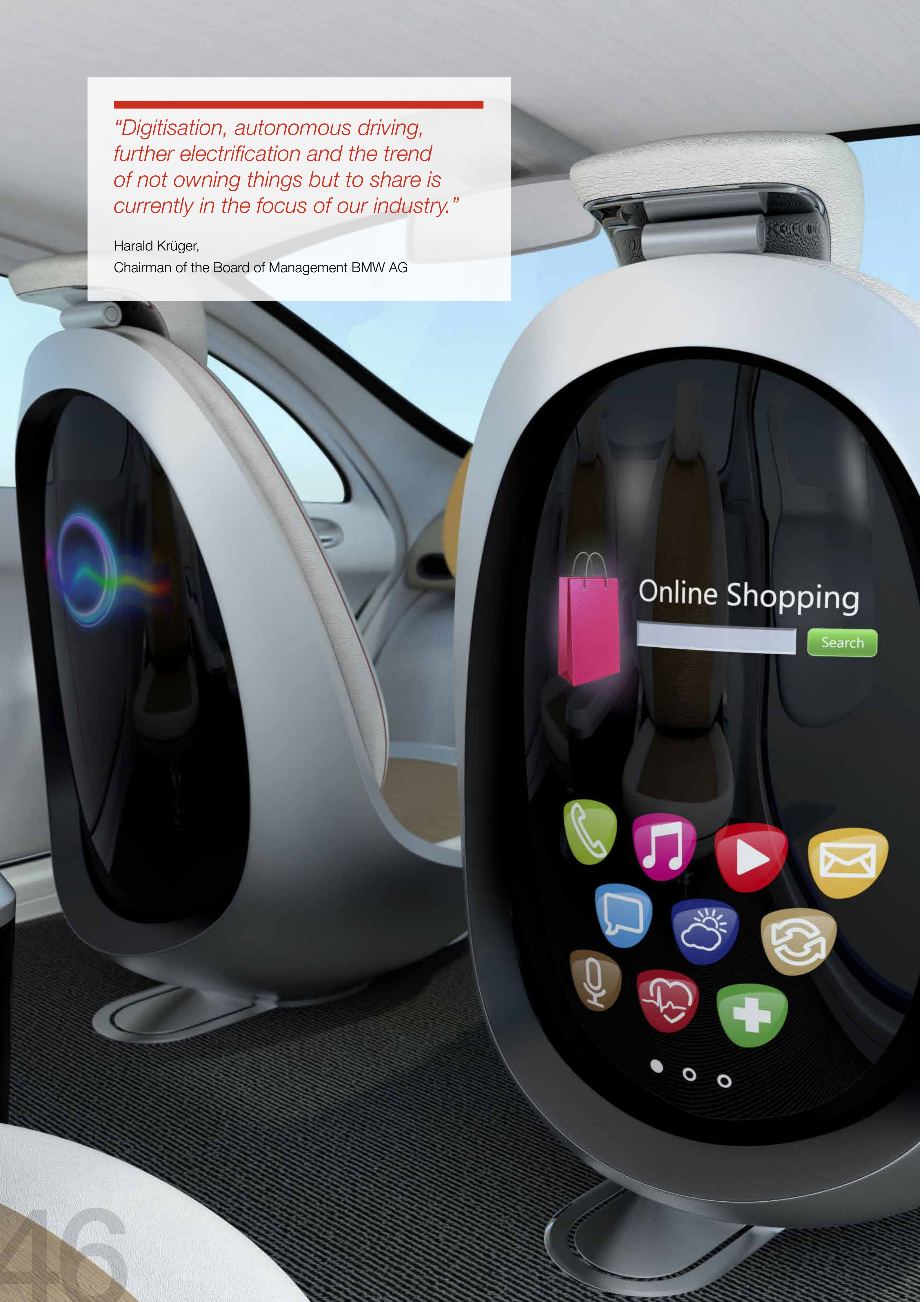
- **More maintenance.** The utilisation of vehicles will increase by 60 percent (e.g. by changing from rail to road or by opening up new customer groups such as young people, the physically impaired, or the elderly). The demand for maintenance and spare parts will increase proportionally.
- **Fewer new cars.** Because of the decreasing number of vehicles sold, the maintenance requirements will be concentrated on significantly fewer vehicles.
- **Greater wear and tear.** However, this reduced number of vehicles will be subject to increased wear (e.g. in the interior). This will result in an additional aftermarket potential (e.g. the retrofitting of seats or displays).
- **Fewer repairs.** The number of accidents will be reduced by more than 90%. The corresponding sales from repairs will also see a similar trend.
- **Customisation of the interior.** Niche providers will specialise in customising the interior of the vehicle to the needs of private or business customers. For example, there will be vehicles for business purposes, for long-distance family trips (e.g. for skiing), or for fun trips with friends on weekends.

Hard price comparison – from the vehicle itself!
Autonomous vehicles will be able to manage themselves. The communication with vehicle care service providers will thus shift from the owners to the vehicles. Through predictive maintenance, appointments can be better organised, and the logistics of spare parts can be better optimised. There will also be new platforms through which vehicles can connect with garages and receive information. If the vehicle is capable of self-analysing which of its parts must be serviced or repaired, the vehicle will obtain cost estimates from several garages to select the best supplier based on predefined selection parameters.

Customers increasingly rely on maintenance from OEM garages.
With an autonomous Level 5 vehicle, passengers will be putting their lives into the hands of the technology, which is why they must be 100% trustworthy. OEM-run garages can therefore be more trustworthy for some customers because their technical knowledge comes from first hand. For the same reason, customers may be willing to pay slightly higher prices because it concerns their own safety.

At this point, it will be important for independent garages to quickly catch up and develop in-depth knowledge of the maintenance and repair of autonomous technology. Otherwise, they risk losing potential customers because of a presumed lack of knowledge. Because the reliability of the parts is in the interests of the owners and users of autonomous vehicles, it may appear more reliable at the beginning to purchase spare parts from the original manufacturer instead of less expensive, non-original alternatives.

All this suggests that both original suppliers (OESs) and OEMs can initially benefit from autonomous vehicles from the customer service business. However, this advantage will also disappear with time, when the trust of the customers in the autonomous technology has matured and the confidence in independent garages and alternative spare parts has increased.



“Digitisation, autonomous driving, further electrification and the trend of not owning things but to share is currently in the focus of our industry.”

Harald Krüger,
Chairman of the Board of Management BMW AG

5. Options for leisure whilst driving

Driving time is free time.
US Americans, like Germans, spend an average of 46 minutes in their vehicles every day. According to our Scenario 3 in which everyone either owns an autonomous vehicle or has access to one via car-sharing or taxis, commuters or travellers will gain nearly an hour per day of additional free time. As already mentioned, the interior of the vehicles will also change, giving the passengers additional opportunities to make the most of their newly gained time.

Fresh opportunities for the entertainment and advertising industries.
This development can create a lucrative market for consumer electronics as well as for the entertainment and advertising industry. Passengers will regularly use infotainment systems and devices (e.g. to stream music or videos). This will open up new possibilities and numerous new advertising spaces for the advertising industry.[16]

Alternative advertising methods, which can also be imagined in autonomous vehicles, are already being applied via the app in Düsseldorf's local transport network. Customers who spend a few minutes watching mobile ads on their smart phones receive a free ticket and can thus save €2.60 in exchange for a few minutes of their time and attention for each trip.

Rolling office.
It's not just the entertainment sector that stands to benefit. Through fully autonomous vehicles, the car will become a productive office environment. With an ultra-fast internet connection, a table, and generous displays as well as relevant applications for video conferencing, messaging, CRM or business analytics, business travellers can do value-added work during the journey.

Passenger cabin is fundamentally important.
For private or business applications, there will be different types of vehicles, which will be distinguished by a passenger compartment adapted to individual needs. Assuming that autonomous vehicles will be mainly electrically driven, the space saved will results in much more design possibilities for designers than today.

Completely new driving experience.
Our everyday driving and travel behaviour will be completely changed by exclusively autonomous vehicles. The driving experience as we know it today will also be different. There will be no longer a need to change drivers on the road, rest at the petrol station, or stress over hours of traffic jams. On top of that, we can use the time in the vehicle for things that we really like to do.

6. Cities are evolving

Our cities are currently full of streets, vehicles, and traffic jams. There are street signs and traffic lights at every corner. Our highways are full of construction sites. High-traffic, narrow streets often lead through small towns and villages.

Road infrastructure

Fewer street signs.

The introduction of fully autonomous vehicles means that much of the infrastructure we know today will become obsolete. Vehicles and other components of the traffic management system will be able to communicate with each other thanks to IoT technology. The vehicles will also be equipped with highly detailed maps, which will synchronise themselves in real time with a cloud or with other vehicles. These high-resolution maps will always contain up-to-date data such as speed limits, traffic rules, or parking space information. Most road signs will therefore no longer be necessary. However, they will not disappear completely from the streets. Pedestrians or cyclists will also need physical signs in the future, but the number of signs will decrease significantly.

Traffic control system.

A virtual and superior traffic control system – one that optimises traffic rules, traffic flows, and speed limits based on current traffic conditions and informs and directs the autonomous vehicles via data exchange – is also conceivable. To this end, there will have to be an institution that regulates traffic centrally.

Automatic speed limit.

If, for example, certain regions are experiencing black ice, the overarching traffic guidance system will be able to signal speed limits for these areas and autonomous vehicles will adapt to this. Another example is the speed limit in front of a school. On a school day, it can be set to 30 kilometres per hour. At the weekend, when there is no danger to the safety of the students, the speed limit can be increased.

Automatically detect and report street damage.

Last but not least, considerable improvements can be achieved in infrastructure problems. Using data obtained in vehicles, it will be possible to recognise necessary infrastructure projects at an early stage and plan them according to the volume of traffic. For example, the way an autonomous car's suspension systems dips or bumps can provide insights into pothole formation.

Vehicles will "anticipate" the habits of pedestrians

Driving whist looking ahead – in the truest sense of the word.

It is conceivable that vehicles will soon be able to anticipate the next steps of pedestrians or the path of cyclists. When autonomous vehicles are given the information on the habits of these road users, they will be able to predict their behaviour at certain points using artificial intelligence. Another possibility would be to use route information from the smartphones of road users to predict behaviour.

By using this data, the vehicle will learn, for example, that based on statistics, on a warm summer day, many people will cross the road at a certain point at the exit of the park in order to get to the ice cream parlour on the other side of the road. Accordingly, the vehicle will know that it must be attentive and be prepared to stop for pedestrians.

Route data for more safety.

The transmission of route data from the pedestrian's smartphone to the vehicles in the surrounding area will provide a further possibility for the safe design of road traffic. If a person leaves home to go to the supermarket, for example, this route data could be transmitted. The moment the person arrives at the place where he/she must cross the road, the vehicles approaching the crossing will receive the appropriate signal, stop, and let the person cross the road. Without this information, the vehicle would have to rely solely on the accurate interpretation of its sensory data.

Less space for vehicles, more habitat for people

Green spaces, not parking spaces.

Vehicles from car-sharing providers or autonomous taxis will be almost always on the job in order to minimise costs and optimise resources. As a result, almost no parking space will be required in metropolitan areas. According to investigations conducted by Rosenzweig and Bartl in Ann Arbor, Michigan (2015)[17] , only 25 percent of the car parks required today will be needed in times of autonomous vehicles. Even vehicles in private ownership will be able to drive independently to parking spaces outside crowded city centres after the owner has gotten off at his/her destination.

This will leave more space for parks, green areas, and pedestrian zones, resulting in completely new approaches from a city planning perspective. Pedestrians and cyclists will be able to move much more safely in the cities, which will significantly increase the quality of life in conurbations.

Not least, paragraph 37 of the Land Building Regulations will be obsolete: ‚For the construction of buildings with apartments, a suitable parking space for motor vehicles is to be established for each apartment (necessary parking space).‘ Fewer car parks (including those underground) will make construction easier and cheaper and provide more space for living – even if one only considers how many detached garages could be demolished.

7. Positive effect on the environment

In the future of autonomous driving, one must also consider the possible effect on the environment. The transport sector is one of the main causes of emissions of greenhouse gases. In the US, about 27% of harmful emissions can be attributed to this sector.[18]

Lower energy consumption.
Cars will remain inefficient as long as they are driven by humans. A human takes the wrong route and has to travel additional kilometres. A human will have to look for a parking spot or get stuck in a traffic jam. A human will accelerate too much only to brake shortly afterwards. Autonomous vehicles will be much more efficient. With car-to-X communications and sophisticated real-time road maps, vehicles will no longer have to search for a parking space and will not waste as much time in traffic jams.

„If you have a fully autonomous car that communicates to other cars and traffic signals, then it can drive more smoothly, much better than a human can, and there will be fuel economy benefits coming out of that.“
Dave McCreadie, General Manager Electric Vehicle Infrastructure und Smart Grid, Ford Motor Company[19]

As early as 2011, the Texas Transportation Institute estimated that congestion costs the Americans about seven billion litres of fuel per year. Driving in convoys (platooning) – especially for trucks – is a good way to save fuel. As the result of an autonomous truck‘s shorter reaction times, they will be able to drive with a reduced safety distance and achieve a reduced drag coefficient.

8. Autonomous vehicles take on jobs

As explained in the previous scenarios, the jobs of truck and taxi drivers are undoubtedly threatened by autonomous vehicles. It is also expected that drivers of public transport (e.g. buses or subways) will be replaced by artificial intelligence. Reduced labour costs and an anticipated increase in efficiency are both catalysts for the use of autonomous technology in these sectors.

In which other areas could the use of this technology also make sense? Especially in the case of public sector tasks (e.g. waste disposal, postal services, or food delivery services), it is quite conceivable that autonomous technologies will take over these tasks.[20]

In a pilot project in Australia, Domino’s Pizza is using the DRU delivery robot, making the autonomous delivery of food possible even today. The robot not only looks for the best and fastest way to deliver but can also identify obstacles in its path with its on-board sensors and react accordingly.[21]

Other services could also become superfluous thanks to autonomous vehicles. For example, passengers will be able sleep in the vehicle whilst on a trip, thereby eliminating the need for a hotel room. Breaks to stop for food or visit to a restaurant along the way could also be eliminated because food can be enjoyed right at the table in the autonomous vehicle. Autonomous vehicles will also likely include refrigerators.

These are just some of the most striking effects that autonomous technology could have on jobs and business models. Autonomous driving will have a major and wide-ranging effect on our daily lives. These points are therefore only representative sample of the whole picture.

9. The most important facts about Scenario 3 at a glance

SCENARIO 3 – a world with exclusively fully automated vehicles

Car-sharing
- Part of everyday life
- Car will be used and not purchased
- The car will come to the customer

Challenges for car manufacturers
- 12% reduction in new car sales
- Less brand loyalty

Aftersales in the future
- 90% fewer accidents and thus fewer repairs
- More maintenance and higher wear and tear because of 1200% higher rates of use
- Pricing comparisons from the vehicle itself
- Customisation of the interior

Options for leisure whilst driving
- Drive time will be free time – 45 minutes saved daily
- New opportunities for the entertainment and advertising industry
- Autonomous vehicles take on jobs

Cities are evolving
- Road infrastructure with fewer road signs and traffic guidance system
- Vehicles will "anticipate" pedestrians' habits
- Less space for vehicles and more habitat for people

Positive effect on the environment
- More green spaces
- 7 billion litres of fuel saved thanks to fewer traffic jams

"In about 40 years' time, the majority of vehicles in cities will no longer be privately owned."

Dr. Elmar Degenhart,
Chairman of the Executive Board
Continental AG

V. PREREQUISITES FOR AUTONOMOUS VEHICLES IN EVERYDAY LIFE

Although the technology has already been largely developed and is certain to reach market maturity in the next few years, a number of other prerequisites are nonetheless linked to the success of autonomous vehicles.

These prerequisites for the three scenarios considered are of varying importance and have varying degrees of need for action. However, sooner or later, all the prerequisites will have to be fulfilled in order to make autonomous driving a successful model. In order to be able to guarantee these conditions, it will also be necessary for the respective actors from the political, automotive, and energy sectors as well as their associations, public institutions, and society to work together.

Interplay of the success factors for the autonomous vehicle

1. Technological maturity

Autonomous vehicle technology will be embedded in a highly complex ecosystem in which various platforms, systems, or components will be networked with the self-driving vehicle. Data exchange is one of the main challenges faced by the automotive industry and telecom operators. Even if an autonomous vehicle will be able to drive independently, it depends on the reception of data (e.g. traffic information, current reports of road conditions, or safety updates) as well as their local processing and storage.

New vehicle components required.
Considering the vehicle as such, not only the components installed in the vehicle will change, new ones have to be integrated.

- ADAS (Advanced Driver Assistance System) – highly-developed, self-learning central computer
- Lidar (light detection and ranging)
- Radar
- Ultrasonic sensors
- Cameras
- Black box

On-site data.
Many functions for autonomous driving will have to be available locally in the vehicle. The massive volume of data generated in each vehicle cannot be transmitted via the mobile network and processed in a remote backend. Among other things, this includes:

- Local acquisition and fusion of sensor data
- Local, 360° environment interpretation and identification of objects
- Local (real-time) data analysis
- Continuous development of vehicle intelligence with self-learning algorithms
- Reliable control of the vehicle via ECUs (electronic control units) and actuators

Challenge: local data processing and storage in the vehicle.
Autonomous driving will produce terabytes of data every day. Thus, the highly efficient processing and analysis – among other things in real-time – as well as securing the data will be of great importance. These enormous amounts of data will push the existing car IT architecture to its limits. On one hand, real-time data buses with a higher bandwidth will be required. On the other hand, the hardware of the control units and the central ADAS on-board computer will also have to be equipped with a significantly higher computing power. For the fusion of the sensory data from lidar, radar, and various cameras in combination with deep learning approaches, 20 to 30 trillion operations per second will be required.

EVALUATION ALMOST IN REAL-TIME

For example, NVIDIA DRIVE PX 2 technology can be used to improve the performance of detailed maps. With many, sometimes very expensive sensors, large amounts of data can be recorded for offline analysis. The data is evaluated locally in the vehicle, and communication with the cloud is minimised. As a result, the evaluation can be carried out almost in real time – an enormous improvement over the previously long running times of up to several weeks.[22]

Not all data is needed.
Not all relevant streaming data will need to be stored. Rather, it will be important to differentiate which data is still needed so that the vehicle can optimise its future behaviour in different situations (machine learning). The following will have to be clarified:

- **Short-term data:** What data will be needed to deal with the situation at hand only to be deleted afterwards? For example, current temperature, radio station, or the weight of the vehicle interior.
- **Long-term data:** What data will need to be stored because it contributes to the development of the artificial intelligence of the vehicle? For example, braking behaviour on snow-covered roads or the behaviour of road users at specific points of the road (e.g. schools) or at certain times of the day (e.g. just before the beginning of classes)

Software more important than hardware.
In the future, mechanical components will lose their importance, whilst the software will become the most important element in the vehicle. Many vehicle components will therefore no longer have a place in the piece list. This will pose a challenge for some suppliers. Autonomous vehicles will soon become rolling computers, OEMs and suppliers will have to significantly expand their IT and software expertise.

Components in the vehicle – software

ADAS - central, on-board calculator more intelligent than a human being in the future.

Highly developed central computers (ADAS) make processing, analysis, use and storage of generated data possible – within milliseconds. Current ADAS will thus have to be developed further. International standards such as ISO 26262 already provide certain functional safety standards for electrical and electronic systems such as ADAS. They will be used in all phases of the life cycle of safety-related vehicle systems.

Machine learning, which, among other things, is based on deep neural networks, will play a key role in the development of autonomous vehicles. Human drivers learn important traffic rules or deal with critical situations from driving instructors and in driving practice. The autonomous vehicle will also have to learn. Pre-programmed rules cannot anticipate every possible scenario in traffic. The self-driving computers on wheels will not only be equipped with a series of pre-programmed “if-then” but will be primarily dependent on self-learning algorithms and the associated learning abilities.

In the context of Fleet Learning, the behaviour of a human driver is compared with the behaviour of the central on-board computer. At which point in a curve would a human brake? When would the car have braked on its own? If the behaviour at the same geographic position is determined by a large number of vehicles, the optimum braking time can be explored, and this information could be transmitted to all other vehicles that have not yet passed this location. The on-board computers therefore learn from real human behaviour and store this knowledge for comparable situations in the future. The on-board computers will thus be able to rely on a much larger cache of experience and be more intelligent than a single person.

„The whole Tesla fleet operates as a network. When one car learns something, they all learn it. That is beyond what other car companies are doing.“

Elon Musk, CEO Tesla Motors

The ADAS and specially associated, self-learning algorithms (Machine Learning) are a key success factor for OEMs as well as suppliers who want to secure a future-oriented market position in the area of autonomous vehicles.

FLEET LEARNING – VEHICLES LEARN FROM EACH OTHER

A common learning algorithm used in autonomous vehicles ensures, for example, that localisation and differentiation between objects in the vicinity of the vehicle is improved. Also, vehicles within a group (e.g. a manufacturer’s series) will exchange their learned behaviour patterns and thus increase their collective intelligence (Fleet Learning).

Sensors: Lidar, radar, cameras, ultrasonic – better than eyes and ears.

In the autonomous vehicle, the eyes and ears of a human driver are replaced by highly sophisticated sensors. The first is lidar, which can generate a high-resolution 3D image of its immediate surroundings and objects contained therein on the basis of a pulsating laser. Lidar is currently still by far the most expensive sensor of an autonomous vehicle and generates huge amounts of data. Additional long-range and/or short-range radar sensors are installed. These can determine the distance to objects, their angle to their own vehicle, and their relative speeds with considerable accuracy.

In contrast to lidar and radar, cameras can perceive colours and thus recognise surface textures (e.g. speed signs or road markings) and thus classify an object. However, cameras also generate copious massive amounts of data, which must be processed locally in the vehicle and stored selectively. Ultrasonic sensors are used primarily for the immediate surroundings (e.g. in the form of parking assistants).

By combining the four types of sensors (lidar, radar, cameras, and ultrasound) and fusing the sensory data generated, it becomes possible to generate a highly reliable detection of the environment and to determine the driving behaviour of the SDC. Reliability is ensured by cross-validating the acquired sensor data.

Data recording: black box like in an aeroplane.

In analogy to flight data recorders in aeroplanes, the black box in the autonomous vehicle will record all relevant information such as speed, acceleration forces, steering movements, geographic positions, or error data from control units in order to be able to work through the incident as completely as possible in the event of accidents This will allow authorities or insurance companies to objectively ascertain fault and the associated liability issue based on a comprehensive database (i.e. whether the accident was caused by human error or technical failure).

Mechanical components – drive

We also expect profound changes in the design of the drive. Current political, technological, and environmental-oriented discussions strongly suggest that the drive will be electric once complete autonomy has been achieved. With electric motors, two-speed transmissions, and battery modules installed in the vehicle as well as artificial intelligence and new sensory organs that will control the vehicle, the technical priorities will shift.

Highly increased energy demand – where will the energy come from?
Assuming that all autonomous vehicles will be electric the question arises as to where the required energy will come from. For example, assuming an energy consumption of approx. 20 kilowatt hours per 100 kilometres and a total annual mileage of 15,000 kilometres for an autonomous electric vehicle, 3,000 kilowatt hours of electricity would be required from the energy supplier or from its own photovoltaic system. With approximately 46 million registered cars in Germany, this corresponds to an additional energy requirement of approximately 138 terawatts or 46 million two-to-three-person households. This additional power will require significant investments in both public and private energy generation and will offer opportunities for the respective infrastructure providers.

Charging – on its own to the charging station.
After years of standstill, the development and production of the required battery storage has been in a technological upturn for some time and is becoming increasingly affordable. For example, one kilowatt hour of a lithium-ion battery currently costs $200–250. The forecast for 2030 is below $100. Combined with longer battery cycles, the main market barriers will soon disappear.

The recharging process will also provide additional opportunities for vendors because autonomous vehicles will travel independently to the charging station, and no driver will be present to start the charging process. Efficient charging methods will therefore need to be developed. Either there will be a renaissance of the gas station attendant, robots will direct the charging cable on the SDC, or inductive charging stations will be used. Around 2050 or earlier, there will most likely be a moratorium for authorising combustion engines; this will lead to the extinction of today's petrol station landscape. Demand for the petrochemical products will also decrease.

Networking the vehicle with the environment

Navigation: real-time maps and satellites.
High-precision, dynamic real-time maps can control the vehicle to decimetre accuracy and will therefore be indispensable for autonomous driving. Real-time maps will provide the best possible route and contain up-to-date data on traffic regulations, road signs, possible obstacles, or road conditions.

The importance of accurate maps for autonomous technology is obvious to OEMs. For example, BMW, Daimler, and Audi acquired the former Nokia company, HERE, in 2015. Competitors like Google have been developing digital maps for years and are continuously refining their content.

SATELLITE SYSTEMS OF THE FUTURE

For a high-precision driving behaviour, autonomous vehicles require accuracies in the decimetre range. Thus, the era of the original American satellite system, Navstar GPS, seems to be finally over. With a position tolerance between five and 15 meters, it is no longer able to provide the necessary accuracy in the navigation.

The European satellite system Galileo currently provides one metre of accuracy to the public and one centimetre of accuracy with encryption. By 2019, the ESCAPE consortium, which is based on Galileo, will complete the development of an innovative positioning engine that will meet the high safety requirements of autonomous driving. The first GPS + Galileo receiver chipset with multi-frequency capability suitable for the automotive mass market will be a core component of these positioning engines.

Reasons for satellite-supported navigation.
Why do autonomous vehicles even need satellite navigation? One might assume that roads and surrounding objects can only be identified by built-in sensors such as lidar, radar, or cameras. However, these are insufficient for the following reasons:

- Forward-looking driving: Thanks to the navigation system, the vehicle can plan speed, braking, or steering behaviours a few seconds before the on-board sensor system can even perceive and respond to a curve or intersections. With a navigation system, the vehicle becomes an "experienced local driver" who, thanks to detailed road knowledge, can optimally adjust his or her driving behaviour in contrast to an "out of towner", who cannot benefit as much from anticipating events and is thus less efficient.

- Collaborative driving: With the knowledge of the precise position of oncoming traffic, the system in the autonomous vehicle can decide, for example, whether, a car can be safely overtaken in a curve or behind a hilltop. The same applies to turning into a poorly visible intersection. Here, the precise positioning of vehicles in the vicinity is highly relevant to safety.

The corresponding future technologies will be elementary components of any autonomous vehicle and thus represent a significant market potential.

Connected car backend: faster new features.
Car IT experts will have to develop fully integrated ADAS, sensory, and ECU (Electronic Control Unit) systems that map the artificial intelligence for the autonomous vehicle and its operating system. The connected car backend is usually owned by the OEM and is a mainstay for critical vehicle and infotainment services.

More software specialists are urgently needed. The automotive industry will also have to adapt to significantly faster development and product life cycles – as is common in the IT industry. The Tesla example illustrates this trend impressively. New features or the closing of security gaps through patches are made with over-the-air (OTA) software updates. When the owner or user enters the SDC in the morning, he or she can enjoy new features or simply a new look and feel of the vehicle.

Mobile communications: at least 5G.
Public telecommunication infrastructure will have to adapt to change. Even though an autonomous vehicle can travel without a permanent Internet connection, current LTE technology will not be sufficient for the amount of data exchange required. The increasing use of infotainment and streaming services whilst driving will require better networks with higher performance.

Effective car-to-X communication will require at least 5G mobile technology, which is designed specifically for "device-to-device", an extremely stable and massive machine communication. The forthcoming standard will have to allow data transfer rates of 10 to 20 gigabits per second with extremely low charging times of less than one millisecond – whilst 4G typically operates in the range of 200 megabits per second. This will allow ad hoc data nodes for data exchange between the vehicle, other traffic participants, and components of the IoT.

According to official data, the 4G network coverage in Germany currently amounts to more than 90% of the population. In practice, however, the link quality often leaves something to be desired, even along important motorway sections. Dead zones cannot be permitted in times of autonomous driving. The provision of 5G in Europe is estimated to require approximately €300–500 billion in investment and be available around 2020.

Car-to-X-communication for more efficient traffic flow and fewer accidents.
The IoT and car-to-car communications will enable traffic to flow more smoothly, and accidents will be reduced. More efficient traffic flow will produce less CO2 and nitric oxide emissions or will require less energy in electromobility, thus contributing to environmental protection. The declining accident rates will be both an opportunity and a challenge for insurance companies because liability claims will be reduced to a minimum. Will insurers become obsolete in times of autonomous driving?

Vehicles will not only communicate with each other but also with their entire ecosystem (e.g. traffic lights, parking garage barriers, or charging stations). For such direct communication with the vehicle, all possible communication points will have to be equipped with units for transmitting and receiving data. This will create a whole new market with considerable potential.

Transportation infrastructure – vehicles communicate with one another.
Through the use of autonomous technology, it will be possible to minimise physical traffic signs and traffic management elements can be minimised. Traffic regulations and information will simply be sent to the SDC and dynamically updated. There will therefore need to be an overarching institution that centrally regulates traffic on the basis of an IT platform.

IT PLATFORM INSTEAD OF SIGNS AND TRAFFIC LIGHTS

In the future, an IT platform will contain extensive information on location-dependent traffic rules. Between which geocoordinates along which road is there a 30-kph zone? Where along the road is stopping strictly forbidden? Which rules of right of way are in effect at which junctions?

Even the complete elimination of traffic light systems is conceivable. Vehicles will coordinate with each other and, depending on the traffic volume, dynamically regulate the right of way in the sense of the best solution for the whole. The same could apply for speed limits around a school. Outside school hours on workdays, on weekends, or during holidays, the limit could be increased from 30 to 50 kilometres per hour without the need for physical road signs.

The current traffic rules could be dynamically projected onto a screen or the panes of the autonomous vehicle so that they are known to the passengers, thus enabling them to understand the driving behaviour of the SDC.

Will structural road boundaries (e.g. guard rails) become superfluous? Once a highly developed and thus highly reliable autonomous vehicle fleet exists, this is quite conceivable. By eliminating these structural limitations, it will also be possible to make the use of the roads more flexible depending on traffic volumes.

Test drives.
From a statistical point of view, around five billion kilometres of test drives will be needed to make SDCs as safe as vehicles controlled by humans. In the face of this enormous number, OEMs simulate test drives in virtual environments that simulate reality and corresponding applications (traffic situations) as precisely as possible. Here, gamification will play a lasting role.

2. Safety

Cybersecurity – central to broad acceptance.
In the face of increasing cybercrime, cybersecurity will be an important issue in the context of autonomous driving. For example, more than half of Generation Y (born from 1980 until the turn of the millennium) fears that networked and autonomous vehicles can be hacked. In 2015, a Jeep was hacked, which resulted in an accident. Since then, it has become more than clear how dangerous security vulnerabilities can be. For the full acceptance of the new technology, the protection against hacker attacks and the confidentiality of data will have to be guaranteed.

Car theft can also be made easier by hacking; this can cause considerable economic damage. Cyber insurance sales are expected to rise from $2 billion in 2015 to $7.5 billion in 2020.

Tesla was one of the first OEMs within the automotive industry to implement the OTA technology in the vehicle. The classic OEMs have so far had difficulties with this, especially for reasons of security. However, the demand has now been recognised, and work is being done on a rapid implementation.

Over-the-air software updates – not just for security.
Anyone who owns a computer knows that software is constantly exposed to viruses, Trojans, or malware and must be kept up-to-date. Autonomous vehicles will be connected to the outside world via various interfaces such as 5G/M2M or Bluetooth. This means that there are a correspondingly large number of hackers and malware entry gates. A hacked vehicle is a direct hazard not only to its occupants but also to its surroundings. OEMs will therefore need to install software updates (e.g. patches) on a regular or ad hoc basis.

Software updates will not only close security gaps in the vehicle but also enable new infotainment services, site-dependent advertising, or the updating of map materials. In addition, new findings from traffic and vehicle data collected by numerous autonomous vehicles will be made available to all other vehicles – the keyword being „Fleet Intelligence". This will make the vehicle more intelligent and secure.

REASONS FOR OTA UPDATES

There are at least two good reasons for providing OTA updates:

1. Frequency of updates. Software must be up-to-date at all times – with regular updates that close security-relevant gaps and provide functional enhancements. If the vehicle had to visit a repair shop each time for an update, security could not be guaranteed promptly.

2. Habit. By now, we are accustomed to receiving updates via mobile networks from IT and entertainment electronics. Our smartphones, tablets, computers, and other electronic devices that are constantly connected to the Internet (e.g. routers or flat screen TVs) independently update their firmware, operating systems, and apps or even perform complex business applications. The demand or habit of consumers in the consumer electronics sector will now be transferred to the automotive sector.

Automotive players as data protection and IT specialists.
Security experts criticise OEMs for constantly striving for safe driving yet ignoring data security. The data produced by autonomous vehicles is valuable and sensitive. It contains information about movement patterns, personal habits and preferences, financial data, and much more. At this point, it could be an enormous advantage to integrate best practices and technological approaches from the IT industry into the entire solution architecture of the autonomous vehicle.

The significance of data protection is individual. It varies according to age, gender, level of education, and geographic origin. These different needs will require manufacturers and service providers to react and give the various user groups the freedom to choose the degree of data sharing with third parties. OEMs and vendors can benefit from tried and tested processes from the IT industry.

3. Legal framework

Current legal situation in Germany.
In order for autonomous vehicles to be able to conquer the market, a political discourse about new laws, traffic regulations, security, and liability issues will need to be held. Until 2014, it was strictly forbidden to use self-driving vehicles in Germany and 73 other countries that signed the Vienna Convention on Road Traffic in 1968. The driver was required to have control over the vehicle at all times. This convention was amended in 2014 and now allows for the use of autonomous vehicles but only on the condition that the driver can take control at any time.[23]

In Germany, corresponding laws that would bring the amendments to the Convention into force were introduced in 2017.[24] Level 3 and 4 autonomous vehicles are permitted, but Level 5 ones are not.

International legal situation.
The legal situation is different in the US, which has not signed the Convention. The regulations therefore are not valid there. Each state establishes its own laws on the use of autonomous vehicles. Since 2012, only a few states have considered autonomous driving in their legislation and approved the testing and driving of autonomous vehicles.[25]

Although China is known for its fast and numerous innovations, it has also not signed the Vienna Convention and is struggling with laws that allow the testing of autonomous vehicles on motorways.[26]

Transnational cooperation necessary.
A coordinated transnational approach is necessary so that, in the case of cross-border traffic, the vehicles can be operated as in the country of origin and harmonise with foreign traffic.

4. Social acceptance

Acceptance curve.
The best technology and the best price are of no use if a product is not widely accepted by the target customers. A part of the current population is suspicious and partly afraid of autonomous driving. It is understandable that people will need time to get used to entrusting their lives to a machine.

"Over 90% of all traffic accidents are human failures. And then it will start in the favoured residential areas, say Berlin's Prenzlauer Berg, for example, that parents do not want you to go with your normal car because they pose a traffic risk"[27]

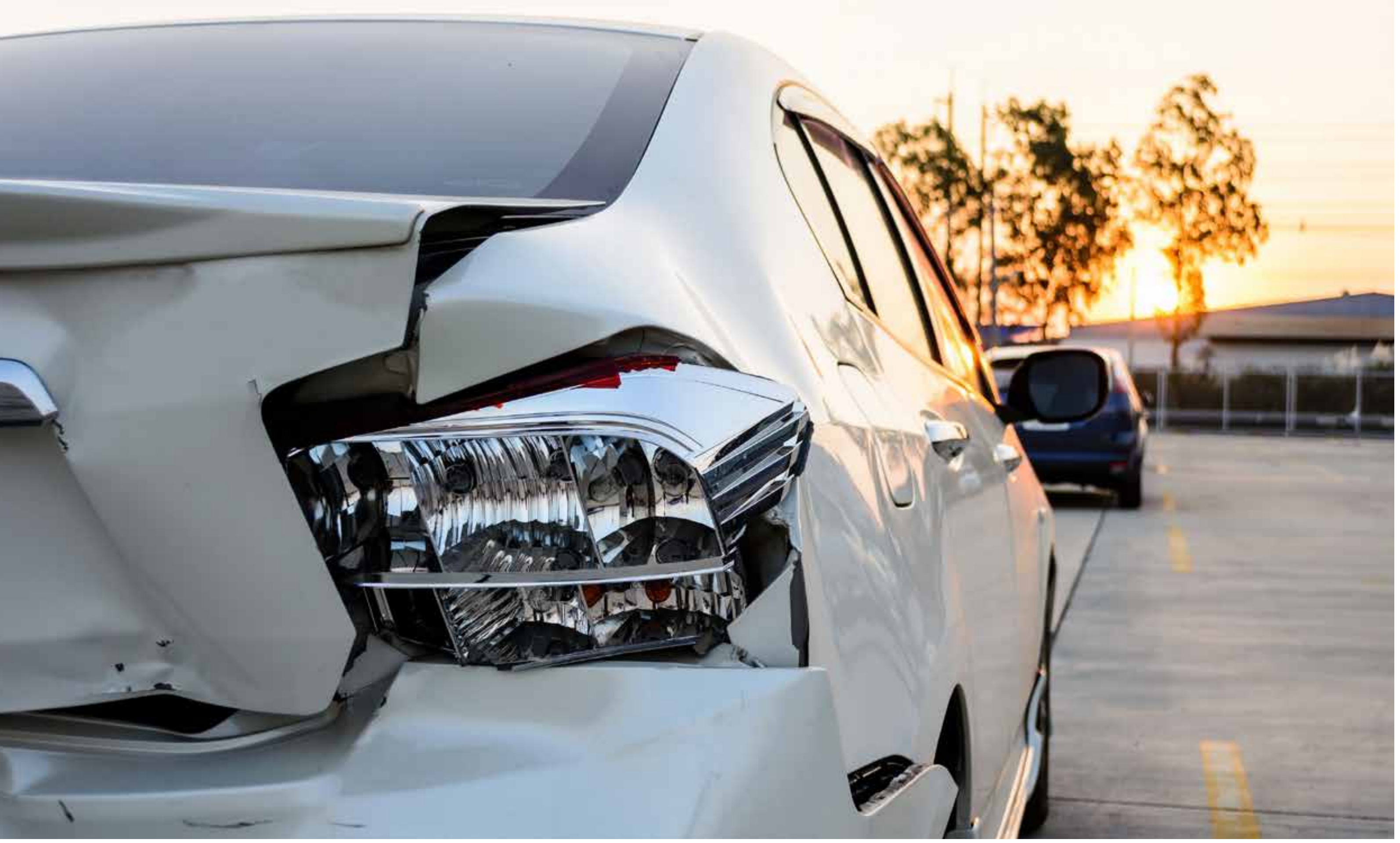
Philosopher Richard David Precht

With the invention of the safety belt, people were also sceptical of the new technology. Today it is clear that safety belts save lives, and they have become a matter of course. Another example is the autopilot in an aeroplane, which flies the aircraft independently. Again, we have become accustomed to the fact that a machine controls the aircraft and that the probability of an error is minimised.

As has often been the case with technical developments, it will be mainly the younger generation that initially shows more interest and convinces other age groups of the technology. The market penetration will begin gradually and then later – after a certain inflection point – exponentially. Acceptance is the result of a longer-term learning process in society. When people come into contact with technology and recognise its potential for saving lives, acceptance also increases.

FORECAST FOR MARKET PENETRATION

Like other innovations, autonomous technology will have a similar acceptance curve, but this is expected to be longer. For the fixed-line telephone, it took about 90 years from the invention to 80% market penetration in the US. Electricity took around 70 years and the smartphone only 10. Our forecast period for a comparable market penetration of autonomous vehicles is 4 to 50 years, not least driven by the great cultural change and the size of the investment volume.



No acceptance of accidents by self-driving vehicles.

Critical to acceptance is, above all, the question of whether we will be able to accept accidents and damage caused by computers as well as accidents caused by human error.

> *“I suspect that the public tolerance for robot accidents will be much lower than it is for human accidents, to me, that looms larger and is more challenging [than the technology].”*[28]

Chris Dixon, Silicon Valley Investor at Andreessen Horowitz

As media reports show, in accidents caused by self-driving vehicles, people are often indignant or even frightened. The most common reaction is that autopilots should be prohibited. On the other hand, few accidents involving conventional vehicles are caused by technical failure. In Germany, around 3,400 people are killed by human error in the approximately 2.5 million accidents per year.[29] These tragedies are widely accepted by society.

Ethical and moral aspects.

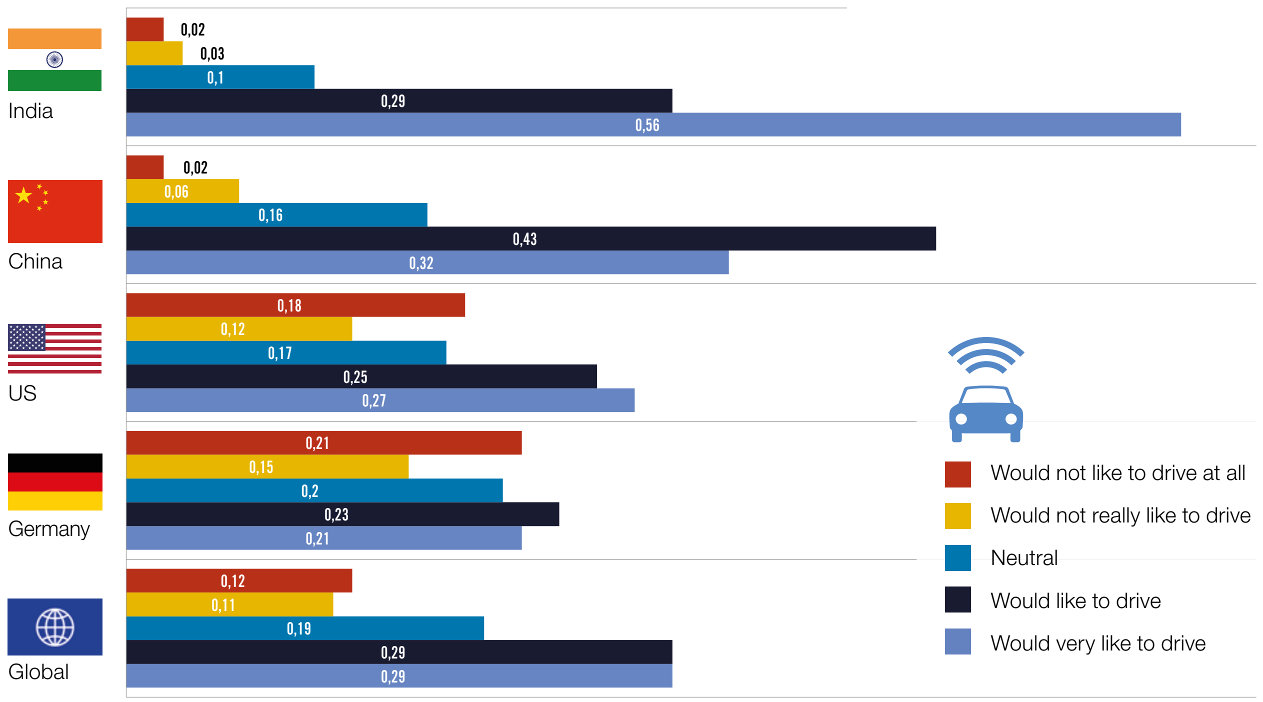
The problem of moral decision-making for autonomous vehicles is also often cited. Philosopher Richard David Precht says, “The self-driving car poses no problem from a moral perspective. With self-driving cars, people always ask how the car will swerve if someone runs across the road. On one side, there are three old ladies and on the other, there’s a toddler. Which is more moral? Running over three old ladies or one toddler? But this issue does not arise for two reasons. First, no self-driving car can make that distinction. Second, I would generally programme the car with a standard setting – in general, swerve left if possible; if left is not possible, swerve right“.[30]

A certain acceptance for the failure of computers or robots will be necessary. The requirement of politics, industry, and society will need to be that autonomous vehicles cause significantly fewer accidents and deaths.

Country-specific Acceptance.

According to a market analysis conducted by the World Economic Forum (WEF), nearly 60% of the world's population would use a fully independent vehicle. The following chart shows the results of the study for the interesting markets of the US, Germany, China, and India:

Would people like to drive an autonomous car?[31]



The result shows a broad acceptance of autonomous driving in the countries surveyed. However, it is not always in equal measure. In Western countries like Germany and the US, it is significantly lower than in the Asian countries like China and India. Especially in India, more than 50 percent of those surveyed would like to use a self-driving vehicle. In Germany, however, this was only 21 percent.

Completely different passenger compartment.
The vehicle interior will also undergo a significant change. The removal of the driver‘s working space will create entirely new possibilities for design and the associated business models. In the future, the passenger compartment will be designed for business or private activities depending on the application.

THE PASSENGER COMPARTMENT OF THE FUTURE – EXAMPLES OF NEW USES

An autonomous vehicle used for a long distance could offer the appropriate entertainment, sleeping, and eating facilities. A vehicle for commuting to and from the office would accordingly be equipped with an office workstation.

Against this backdrop, new providers will emerge – from target-group-oriented interior equipment as well as the respective private and business infotainment services. The use of a video or telephone conference, including application sharing, will then become the norm in the vehicle.

Displays will bring new market opportunities.
In this context, the market opportunities will be mainly in connectivity and flexible display technology. The introduction of displays into autonomous vehicles will also open enormous potential for the advertising industry. Especially in fleets or autonomous taxis, these displays could be used to place (location-dependent) advertising in the vehicle. As usual, the lower the price per kilometre, the more advertising for passengers.

‚Love‘ for one‘s own vehicle must diminish.
Another important issue is the consideration of driving as a matter of lifestyle or hobby. In order for autonomous driving to have a real chance in the future, driving for the sake of driving will have to become less important for people.

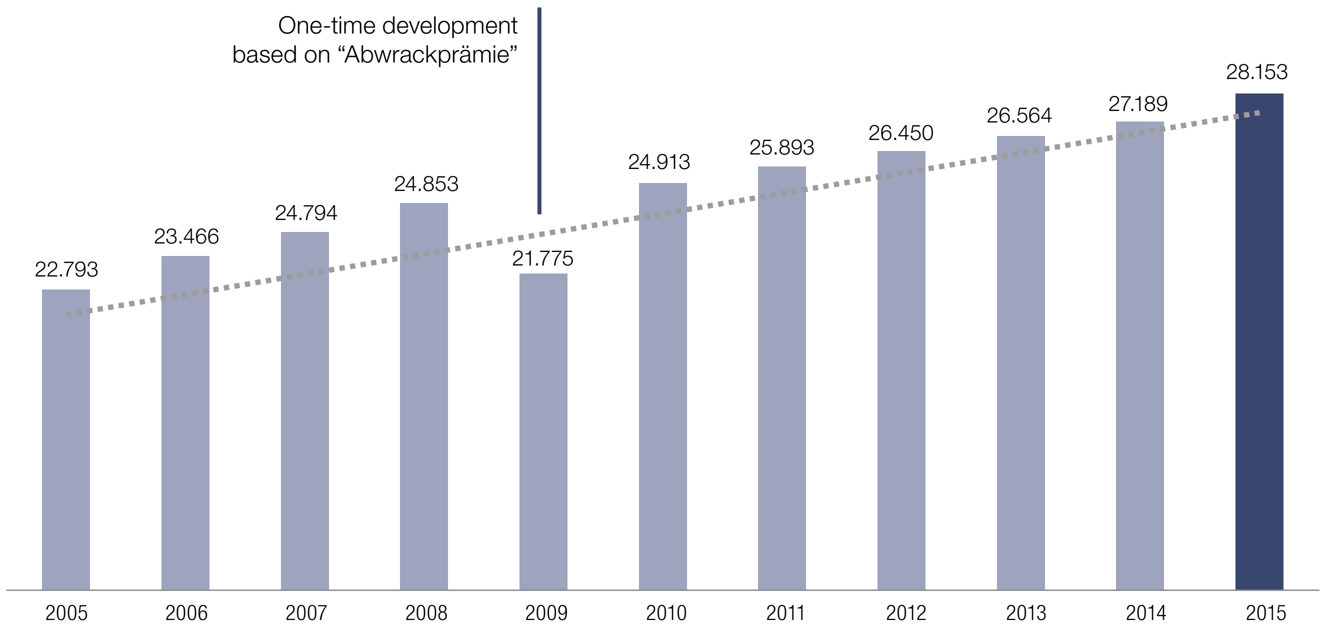
Driving a fast car as well as the tuning and maintenance is still quite important to a lot of people. They find the idea of no longer being able to drive by themselves crazy. For them, driving means more than simply getting from point A to point B. However, it is foreseeable that people‘s habits with regard to driving will change. For Generations Y and Z, the possession of a car and acquiring a driving licence are not as important as for Generation X. Especially in the urban regions of Germany, fewer teenagers than before are obtaining their driving licence.

Driving as a hobby.
However, this does not mean that driving as a hobby will no longer be possible. Riding was not a hobby until the beginning of the twentieth century because horses had almost exclusively been used as an important means of transport. As ‚horseless carriages‘ became increasingly more popular, riding became a hobby for a relatively small number of horse enthusiasts and has remained so to this day.

5. Competitive pricing

Developing car pricing.
The affordability of a technology is just as important as social acceptance. The possession of autonomous vehicles or the use of car-sharing or autonomous taxis will have to be affordable. Germans currently spend an average of €28,153 (list price) on a new vehicle. This corresponds to almost the entire average annual income (the average income in Germany is about €35,000 per year after tax). The average price for a new car has increased by €6,000 over the past ten years. In the 1980s, the average price of a new vehicle was €8,420, which was about half of the average annual income (€16,100 after taxes). In Germany, the average price of a new vehicle has declined only once in the last ten years. This was in 2009, when the federal government introduced the scrapping premium. As a result, many customers bought a new vehicle that they could not otherwise have afforded. This move depressed the average price for a brief time. The main focus was on smaller vehicles.

Development of average new car purchase prices in Germany (in euros)[33]



People today are ready to pay more for vehicles. This development suggests that more money will be spent on cars in the future. This will be important for the spread of the autonomous vehicle.

Cost-driving factors.

The price drivers for autonomous vehicles are sensors and the ADAS. As can already be seen in the market for semi-autonomous driving and advanced driver assistance systems, prices for new developments fall quickly. This means that they will be affordable for more people over time. Only a few years ago the Velodyne's lidar cost about $75,000; the cost of this component is now only around $500. A semi-autonomous Honda Civic with ADAS costs around $20,000. The Tesla Model 3 with autopilot hardware and on-board software, which is currently available on the German market is priced at $35,000, putting it in an affordable segment. Market researchers believe that the complete system for SDCs – after the onset of economies of scale – will cost only about $3,000 more in 2035. The prices of the development phase, which are around $100,000, must also decrease. They should only be slightly higher than those of conventional or partially autonomous models.

Economies of scale.

Another question is how much more an autonomous vehicle will and can cost than a conventional vehicle. The price of autonomous vehicles will be competitive if and when the ratio of price to annual income is similar to today's and the amount to be spent on ownership or use of an autonomous vehicle seems to be economically viable to people.

Launch in the premium segment.

Like most technological innovations in the automotive industry, autonomous vehicle technology will also be introduced in the premium segment. However, here too, the willingness to pay will be limited. The maturity of the technology and associated scaling effects will drive the expansion into the mid-class and small-car segment, thereby making it financially viable for a broad customer group. The efficient round-the-clock use of vehicle fleets will also reduce the price of services such as car-sharing, taxis, or logistical transportation by trucks.

CONCLUSION

The changes that autonomous driving entails are enormous. Thus, the automobile industry is currently undergoing a radical upheaval. It is likely that the industry will change more over the next ten years than in the entire time since the invention of the automobile. Primarily driven by players from Silicon Valley, the technology is developing rapidly.

In this evolution of the automobile, the spread of autonomous driving is expected to pass through three scenarios and develop from conditionally-automated to highly-automated to fully-automated vehicles.

In order to make this development possible, politics, society, and industry will have to be equally involved in order to create the necessary conditions.

In addition to these opportunities, this development also harbours major risks for the classic automotive OEMs and suppliers; the sales market could potentially shrink to 12 percent of the current market as a result of increased vehicle utilisation rates. On the other hand, many opportunities will arise – especially in the development of new platforms around the autonomous vehicle, modern technologies such as ADAS or sensor technology, and new interior concepts.

REORIENT BUSINESS MODELS, ORGANISATION, PROCESSES AND IT WITH NTT DATA

NTT DATA supports the established automotive and supplier industry in keeping pace with this development, defending the global market leadership, and positioning itself so as to make a difference. Integrated total solutions with a well-functioning interplay of processes and IT applications will be necessary for this. The seamless integration of the embedded automotive world with the Internet of Things and the connected car backend will provide a decisive competitive advantage. Moreover, it will be necessary to create the foundations for new business models (e.g. car-sharing) – not only with regard to IT but also security and legal issues. Here, too, we are the number one contact for the automotive industry.

Get in touch with us!

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