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Urban Mobility and Autonomous Driving in 2035

How robotaxis will affect cities and automakers

Contents

Executive Summary

By 2035, personal mobility is likely to have changed dramatically in Germany. Many cars on our roads will be completely self-driving, and a large share of these vehicles will be owned by mobility service providers rather than private individuals. These firms will operate large fleets of autonomous taxis and shuttles and offer door-to-door services, significantly reducing the cost of mobility and leading to major changes in the way we use private cars and other means of transportation.

This study is based on a quantitative mobility model and examines the anticipated effects of a future with autonomous mobility services (robotaxis/shuttles) in Germany. This mobility model posits five developments that we can expect by 2035 based on certain assumptions:

Assumption #1 – Robotaxis will completely change our mobility – autonomous mobility services will become one of the main means of transportation

Nearly one in three trips (32 percent) taken by urban residents could be with the self-driving vehicles of an autonomous mobility service. In terms of the share of daily mobility, these services would be on par with private cars (32 percent) and more than double that of public transportation (14 percent). Overall, driving services in German cities could have a fleet of up to 560,000 autonomous taxis and 180,000 autonomous shuttles, amounting to 740,000 fleet vehicles in total.

Assumption #2 – Price war ignited – autonomous taxi and shuttle rides will be far cheaper than taking a private car or public transportation

Due to savings on drivers and the high utilization rate, single trips could cost 25 percent less than the driving a private car. Users of autonomous shuttles would pay only about half the current price of a ticket on public transportation.

Assumption #3 – The market potential of autonomous mobility services is huge – if regulation allows

The operation of fleets for autonomous mobility services may generate an annual sales volume of up to 16.7 billion euros, one-sixth of the revenue that automakers generate today from new car sales in Germany. To what extent this potential can be realized will depend on the business model of the fleets and future regulation.

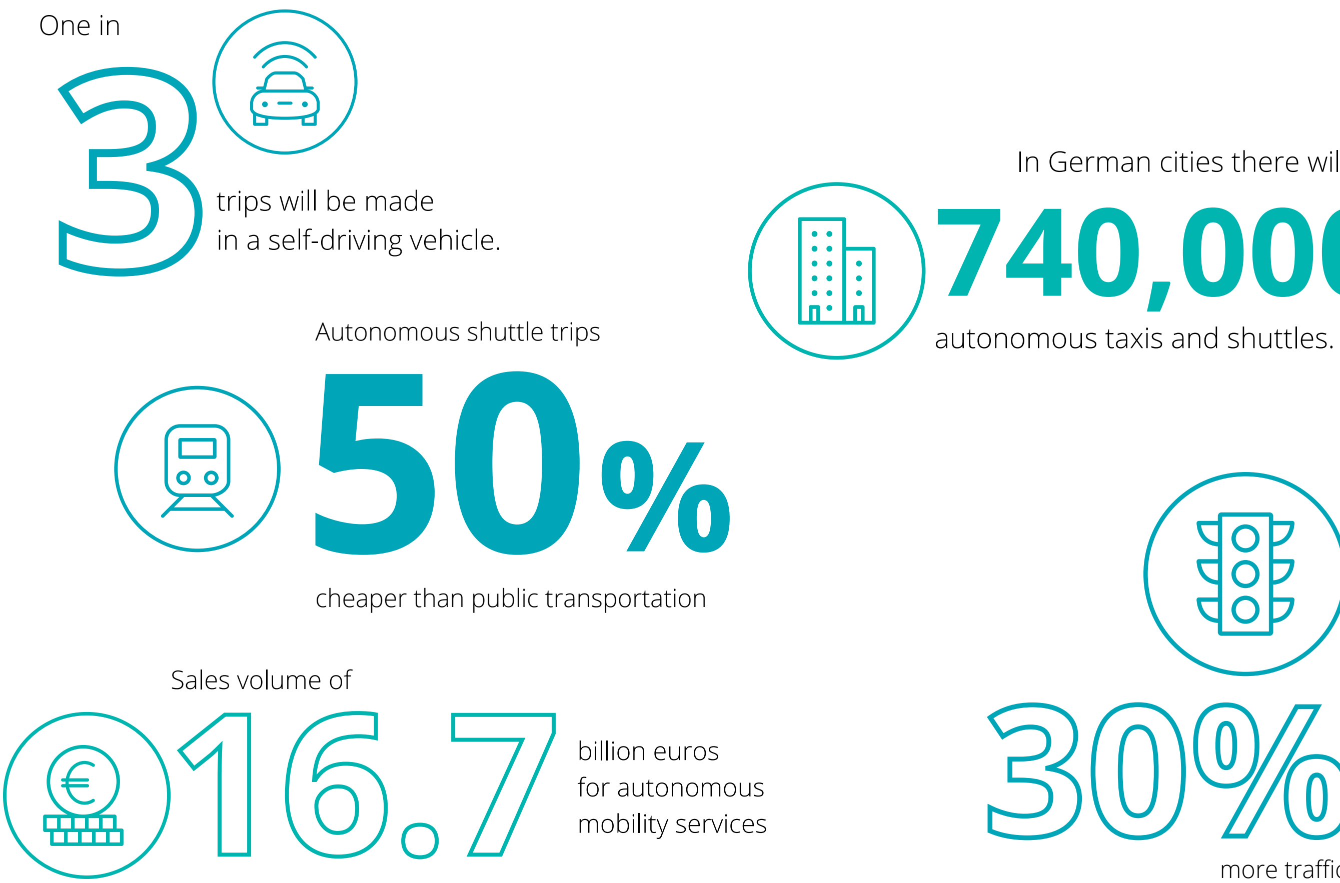
Assumption #4 – Fewer vehicles, but more traffic in our cities

In German cities and metropolitan areas, more and more people will choose to opt out of car ownership. The urban vehicle population could shrink by a total of three million passenger cars (-20 percent) by 2035. The introduction of autonomous mobility services, however, could lead to an increase in the overall use of vehicles. The number of vehicle kilometers driven would increase from 26.7 to 32.9 per person (+23 percent), expanding the traffic volume by up to 30 percent at the same time. At peak times, we could see up to 40 percent more vehicles on the roads.

Assumption #5 – The risk of gridlock is growing – increased use of vehicles leads to an increase in congestion

With more traffic, we can expect traffic jams to occur more frequently and the average speed in cities to decrease by 10 percent. Travel times during the morning rush hour would increase by an average of 2.5 minutes per trip – for all road users.

Fig. 1 – Urban mobility in German cities in 2035: key figures



Assumptions made in the model calculations

1. State of the art: By 2035, we will be able to drive new cars completely autonomously without any human intervention.

2. New mobility concepts: Self-driving technology will enable new mobility concepts, among which we expect two types to prevail – autonomous taxis and autonomous shuttles (shared taxis).

3. Coverage: In our study, travel with autonomous mobility services will be offered exclusively in large urban areas.

4. Drive type: Based on current trends and better charging capability, we assume that autonomous taxis and shuttles will use electric drives from the outset.

5. Free market: We show a maximum scenario in which the market for autonomous mobility services is allowed to develop freely and without government restrictions.

6. Shared road transportation: Private cars and autonomous mobility services will use the same road network.

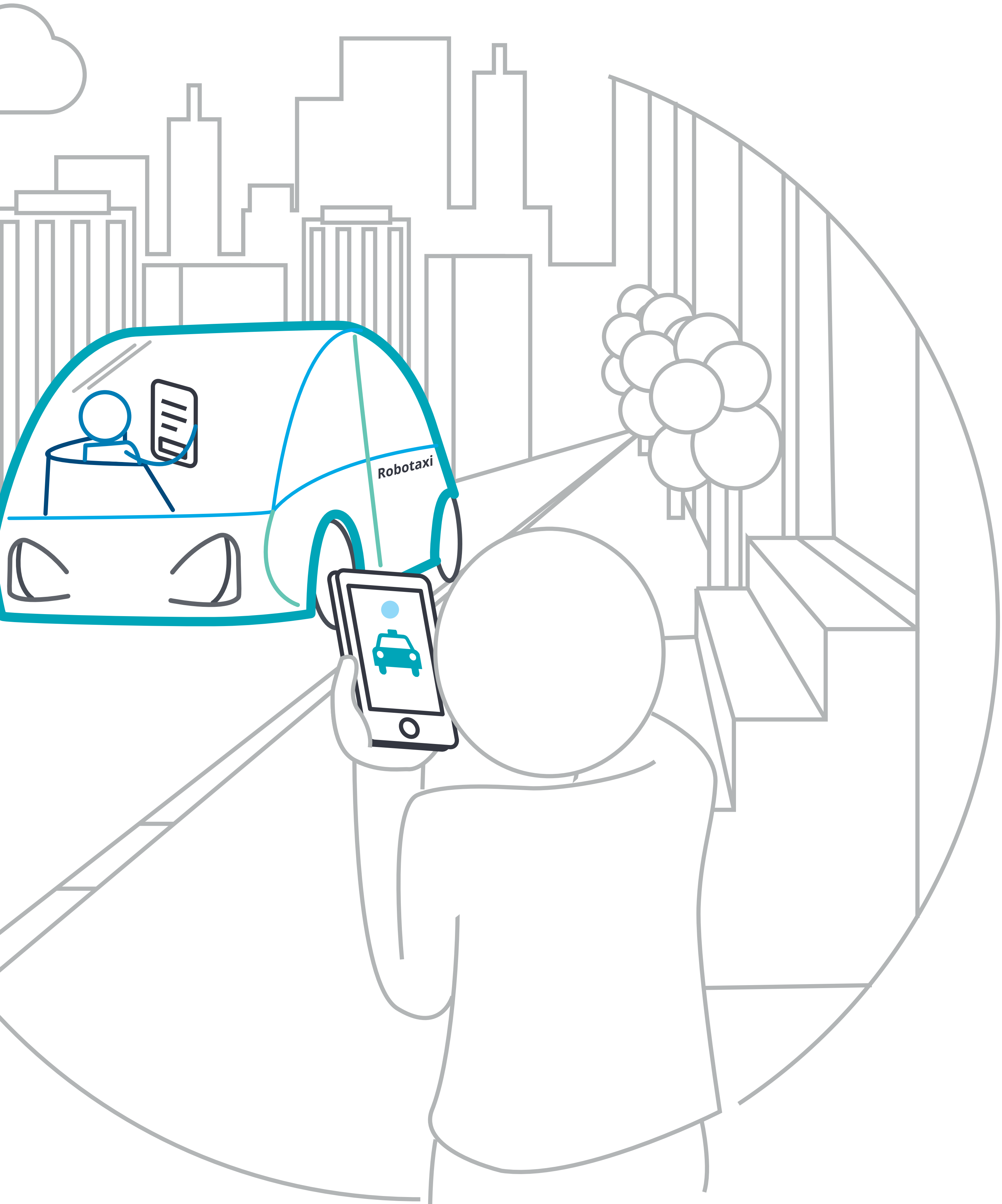
7. Traffic flow: Increased traffic flow due to autonomous vehicles cannot be realized before 2035. Our model assumes that people will continue to drive manually controlled passenger cars and that this will not result in an optimized flow of traffic.

Autonomous vehicles: the mobility revolution

Autonomous vehicles will radically revolutionize mobility in our cities. Mobility services using autonomous shuttles and taxis will create new mobility patterns and put pressure on transport prices.

Tall vehicles with lots of glass but no steering wheels, futuristic touch displays and interiors reminiscent of a living room – the sparkling clean cities of the future will transport all passengers in self-driving vehicles and result in a great many improvements: fewer accidents, fewer traffic jams and, ultimately, fewer vehicles.

Thanks to the recent successes of various automakers in semi-autonomous driving on normal roads, the future of mobility is a subject of great debate. Our mobile future appears to be within reach: a new generation of autos without human intervention.


Robotaxi

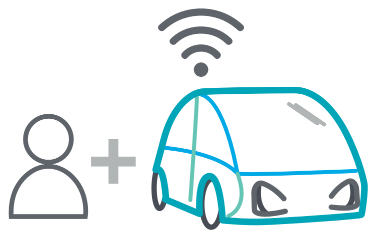
New mobility models are emerging: autonomous taxis and shuttles

In fact, fully autonomous vehicles without human intervention (and in some cases even without a steering wheel or pedals) will cause major disruption. They will offer individual mobility to absolutely everybody. Passengers will not need to have a driver's license or even be able to drive, and they can accomplish other things during the journey. The vehicle will continue driving on its own after the trip, no longer needs a parking space, and can therefore be used to transport large numbers of people simultaneously.

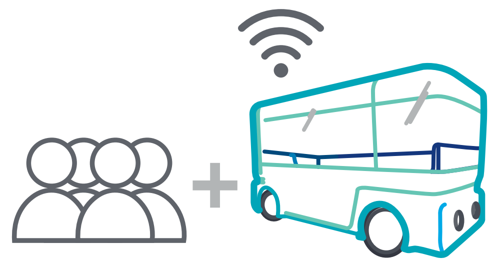
This complete autonomy makes it possible to operate and easily scale fleets of self-driving vehicles. They compete directly with taxis, public transportation, and private vehicles to transport people conveniently from door to door. Without a driver, they can offer these services very cost-effectively.

Based on the developments of the last two years, we believe fleet operators will offer two mobility models in particular.

Fig. 2 – Possible vehicle types used for autonomous mobility services



Autonomous taxi
(individual rides to a single destination for up to two people)



Autonomous shuttle
(shared ride with different destinations and max. four passengers)

Autonomous taxis, often called robotaxis, will transport up to two people in one vehicle from their pick-up location to their destination. This type of transportation is closest to traditional taxi service.

Autonomous roboshuttles are driverless shuttles that pick up various people en route and take them to their individual destinations. Customers pay less but may have to accept detours and longer travel times. Here, too, people are transported from door to door.

Such vehicles could be booked by app, voice or based on artificial intelligence. In the best-case scenario, artificial intelligence could use appointment calendars and behavioral patterns to identify when a person wants to go where and waiting times would be shorter.

Expected effects of autonomous vehicles and fleets

These services offer attractive advantages for individuals. A car picks you up directly in front of your house and drives you to work, allowing you to make good use of your time during the trip. You don't have to maintain the vehicle, find a parking space or even have a driver's license. Autonomous vehicles will fundamentally change the way people move around.

However, that is not all. Why opt for car ownership if a vehicle is ready to depart at a moment's notice? No matter where you are, a comfortable, quiet, modern vehicle will always be available from various fleet providers.

As is so often the case with disruptive business models in industry or society, public expectations are high and often positive:

Fewer cars, less traffic, less congestion?

We estimate that one self-driving taxi will replace up to ten private cars[1], making one in two vehicles obsolete.[2] With fewer cars, higher utilization rates, and technical inter-auto communications, we also expect to improve traffic flow and reduce traffic volume. The time spent in a vehicle can be used for work or leisure, allowing us to make better use of our commute. There is no need to search for a parking space – the car simply drives on after the trip has ended. In addition, we anticipate that the high utilization rate of sharing concepts will make driving cheaper and private cars obsolete.

Some studies for individual cities, however, predict a rise in traffic volume.[3] What is more, the auto industry is concerned that private and commercial car sales could collapse as a result of the widespread use of sharing services.

Politicians, urban planners, and automakers should not get carried away by the euphoria. It is far more important to make well-founded statements about the impact of autonomous vehicles on mobility and traffic over the next ten to 15 years. Will the effects be exclusively positive or are there also critical issues that we need to start considering now?

> As is so often the case with major changes in society, people have very high expectations

[1] Study by TU Munich 2017, source: Wiwo, https://www.wiwo.de/technologie/mobilitaet/autonome-autos-ein-robo-taxi-kann-zehn-privatautos-ersetzen/19629082.html, accessed on 14.08.2019.
[2] Study by the University of Michigan, Transportation Research Institute (UMTRI): https://deepblue.lib.umich.edu/bitstream/handle/2027.42/110789/103157.pdf?sequence=1&isAllowed=y, accessed on 14.08.2019.
[3] ETH Zurich: http://www.mobilityplatform.ch/de/shop/show-item/product/28135/, accessed on 14.08.2019.

Aim of the study: to find reliable answers for 2035

The aim of this study was to make empirical predictions about mobility in the year 2035 for Germany as a whole based on existing and reliable data. This is the only way to differentiate between wishful thinking and a reliable forecast.

The central questions

1. How much of our daily mobility will involve autonomous mobility services?
2. How many autonomous taxis and shuttles will there be in Germany in the future?
3. How much will the vehicles and rides cost?
4. What effect will autonomous mobility services have on future vehicle fleets and new car registrations?
5. Will autonomous taxis and shuttles really lead to less traffic and less congestion?

Data bases and online experiment

As the first of its kind, our study relies on extensive data to analyze the future market for autonomous vehicle fleets in Germany. Among other things, the following data was included in the model:

- Representative online experiment with over 2,000 potential users on acceptance and willingness to pay for autonomous mobility services
- Current movement patterns and commuter networks in 109 German cities
- Age, population, and employment statistics for metropolitan areas
- Traffic statistics of German cities
- Topography of urban areas in Germany

Data sources include the OECD, government statistics authorities, Eurostat, Germany's ADAC automobile association, and the TomTom Traffic Index.

Comprehensive mobility model for Germany as a whole

Based on the data we collected and collated, our model reflects daily demand for individual mobility in 109 German cities. It shows projected demand for autonomous taxis and shuttles as well as the required supply of autonomous vehicles.

The calculations take into account how mobility changes for different population groups over the course of a day. This includes the preferred means of transportation, distances traveled, and average speeds within German cities depending on the time of day.

As a result, the model uses these urban realities to calculate how many autonomous journeys per hour or per day can be expected and how many vehicles will be required. It calculates the utilization of taxis/shuttles per time of day, the average route per trip and per day, and the associated running costs.

For this approach, we used existing statistical data to make a precise analysis and evaluation of the population structure in Germany (cities, metropolitan areas) and the mobility patterns for 109 urban areas. We identified the areas in each individual metropolitan region that are economically suitable for the operation of autonomous fleets based on population density and movement patterns.

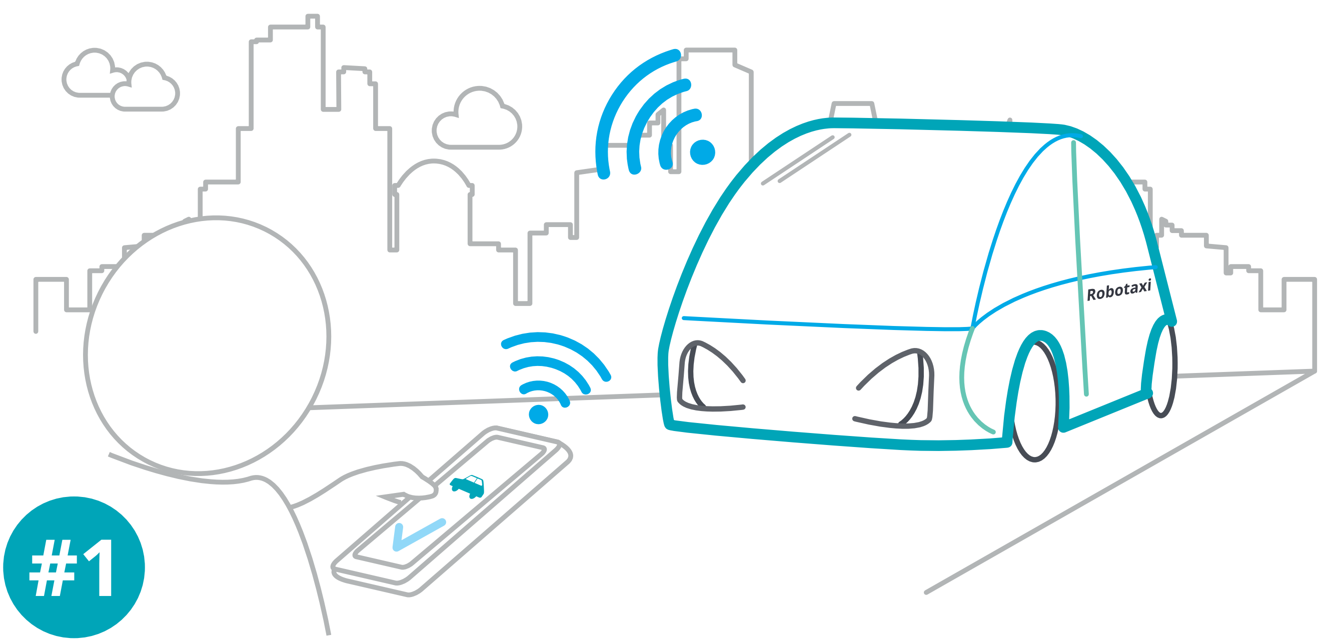
We also compiled detailed cost estimates for the manufacture of the vehicles and fleet operations in 2035 and used them to develop price estimates for the typical trips of a fleet operator. Subsequently, we launched an extensive online experiment with more than 2,000 consumers to determine how many people were likely to avail of such offers.

Further detailed information on the empirical model and the procedure can be found in the appendix entitled "Methodology and data bases" starting on page 32.

Our mobility model analyzes the expected demand for autonomous taxis and shuttles in 109 German cities and estimates the number of autonomous vehicles that will be required.

Five assumptions about urban mobility in 2035

In summary, our model calculations posit five assumptions about potential future changes in mobility, pricing trends, market potential, vehicle population and traffic volume.



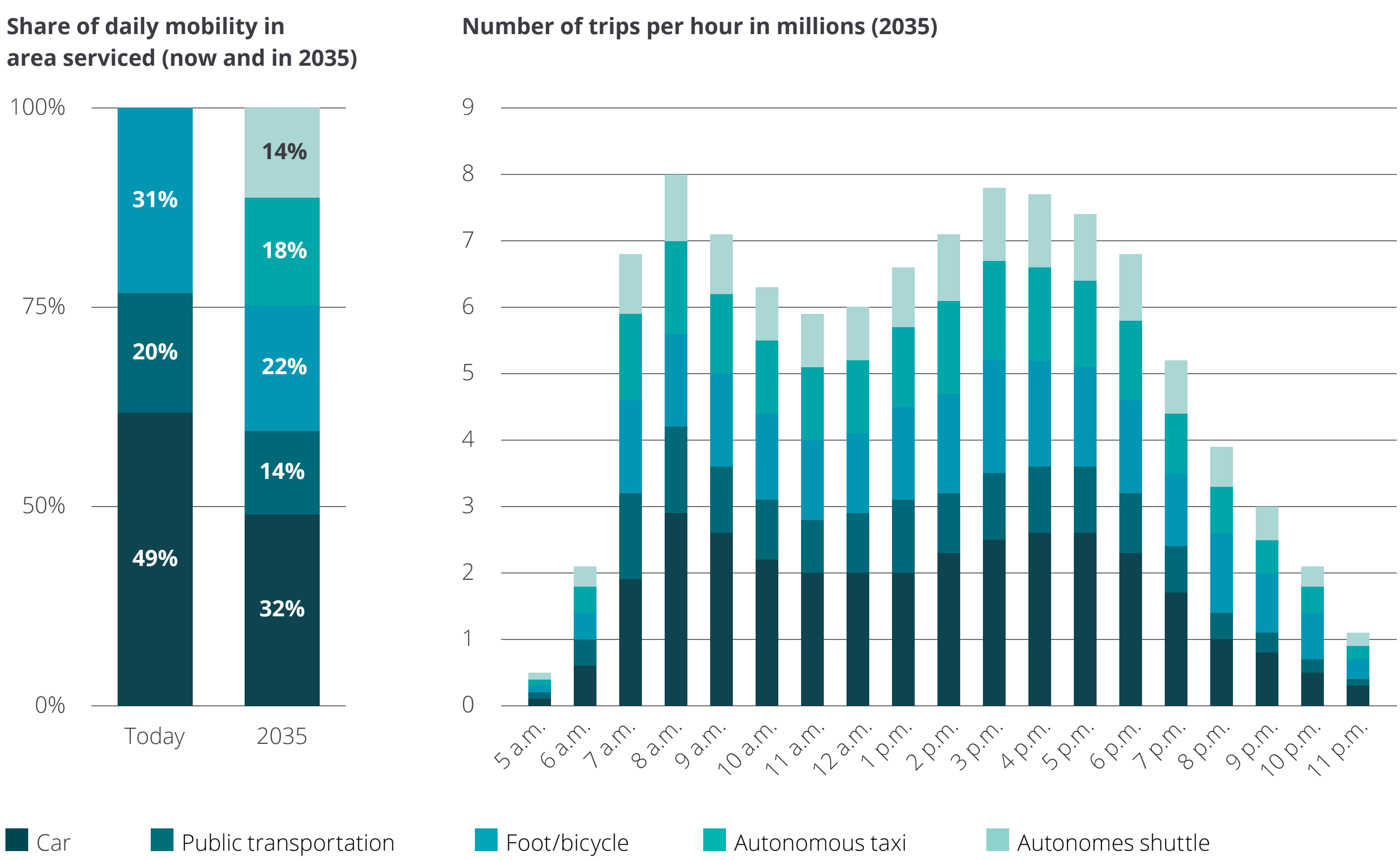
Assumption #1: Robotaxis will completely change our mobility – autonomous mobility services will become one of the main means of transportation

Even though many people are enthusiastic about autonomous driving, one question remains. How many road users would actually be willing to switch over to self-driving vehicles at economically viable prices? For the study, we interviewed over 2,000 people in a representative online experiment. The subjects were asked to imagine various scenarios from everyday life and then decide which means of transportation they would choose. They were also confronted with different travel times and kilometer prices to determine their willingness to pay and switch. Autonomous mobility services transport passengers from door to door without them having to wait more than ten minutes for a self-driving vehicle, even at peak times.

Survey of different user groups: 32 percent of all road users are willing to switch

The findings of our experiment show the enormous potential for autonomous fleets. A total of 32 percent of road users would switch over to an autonomous fleet vehicle if they had to wait no longer than ten minutes for its arrival and fares were charged according to our calculations (see assumption #2). Urban residents would therefore take one in three trips with an autonomous mobility service. At 18 percent, the acceptance level of autonomous taxis is slightly higher than that of shuttles, though the cost would also be higher.

Fig. 3 – Share of daily mobility by means of transportation in German cities and number of trips by means of transportation and time of day



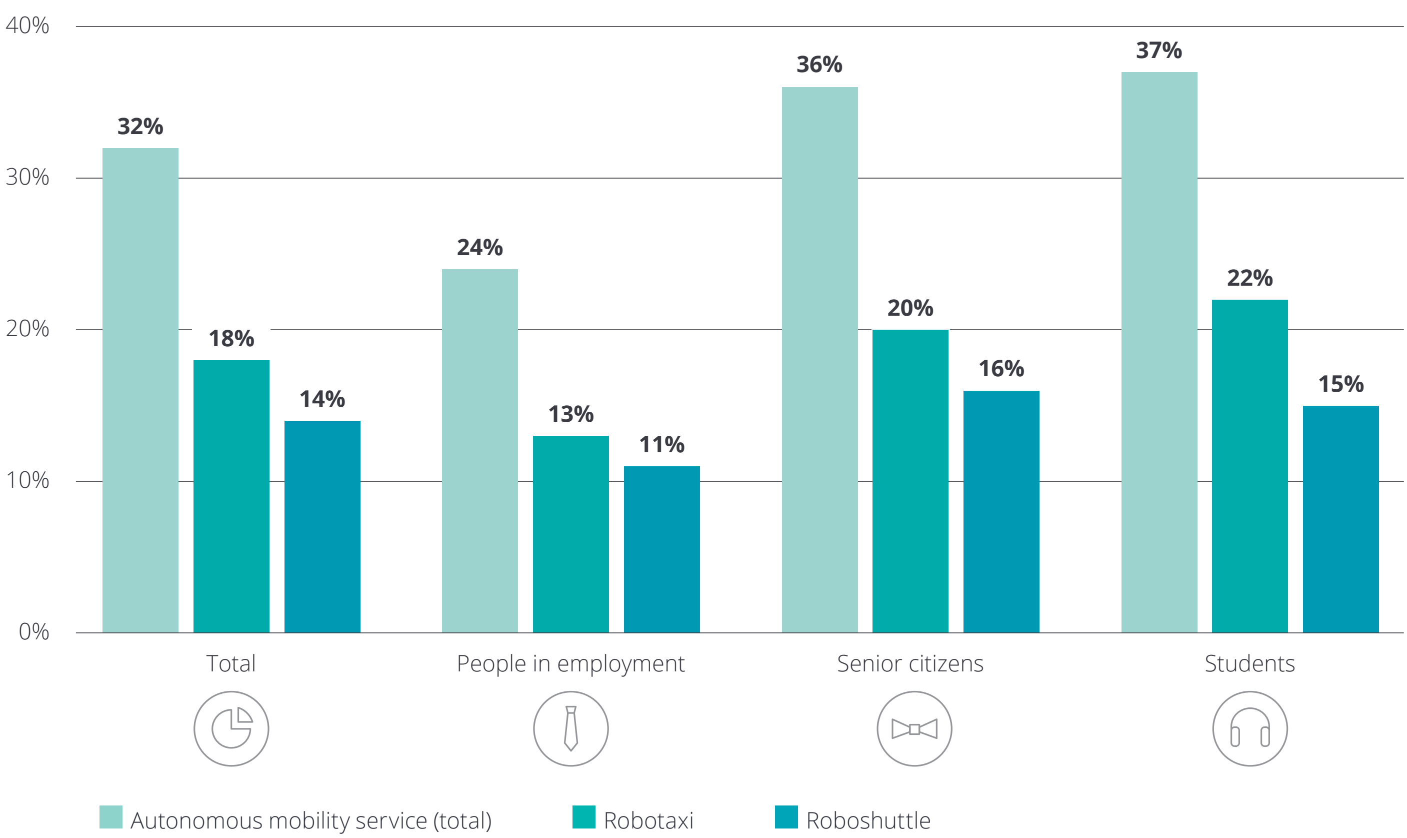
Source: Mobilität in Deutschland, Deloitte Research

Most autonomous vehicles would be required between 7:00 and 10:00 a.m. and between 2:00 and 6:00 p.m. At peak times in the afternoon, some 2.6 million people would use autonomous mobility services.

However, only 24.4 percent of people in employment would switch to an autonomous mobility service. The percentages are much higher among senior citizens and students: 36 percent of senior citizens and as many as 37 percent of students indicated that they would switch. Young road users in particular are much more likely to take an autonomous taxi (22 percent) than a shuttle (15 percent).

In 2035, autonomous fleet vehicles will be used for one in three trips.

Fig. 4 – Use of autonomous mobility services by age group based on our online experiment (with 2,000 participants and corresponding waiting times and prices*)



Source: Deloitte Research

* Note: This scenario assumes a maximum waiting time of ten minutes plus a price per kilometer of 34 cents for robotaxis and 15 cents for roboshuttles.

Car drivers are the most willing to switch to autonomous mobility services – and people in employment the least willing

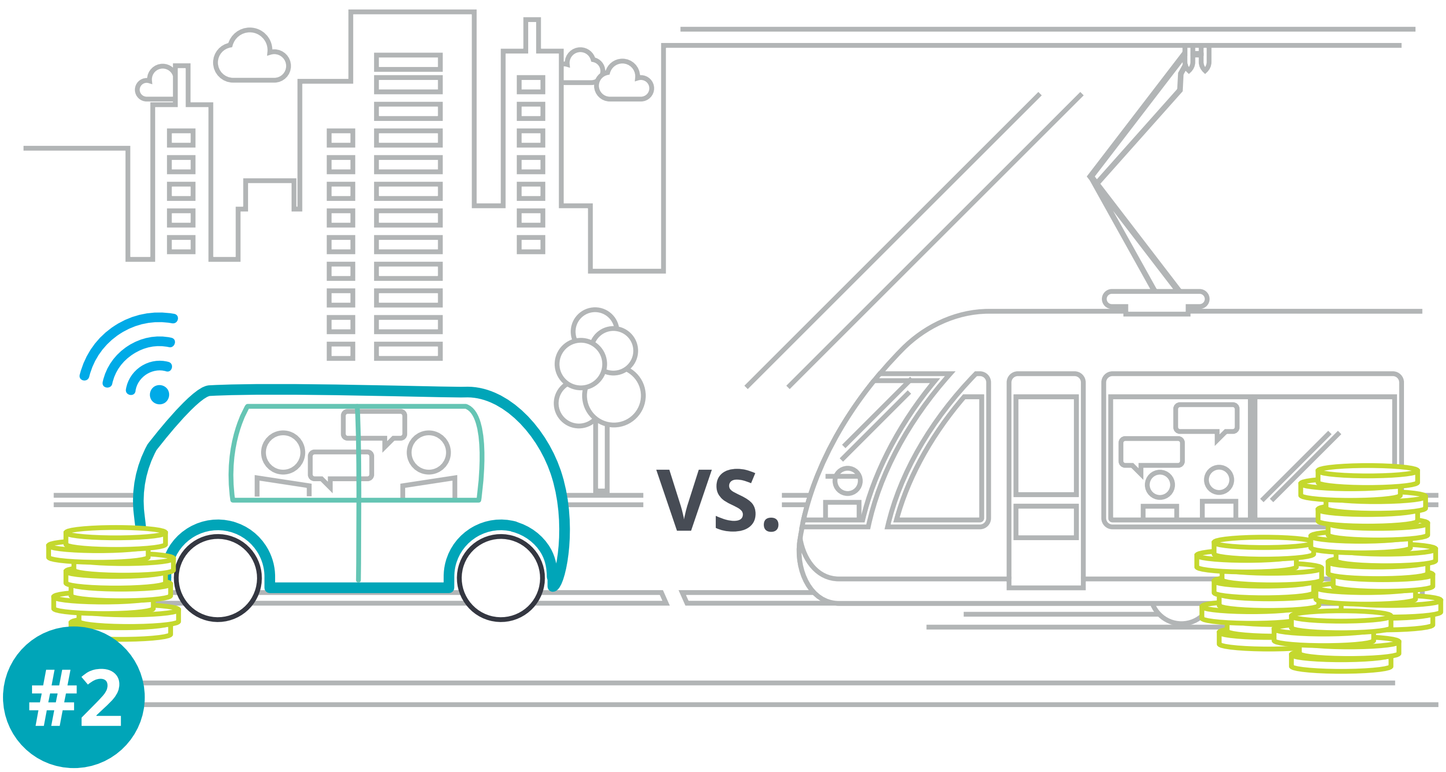
People who currently travel by car as drivers or passengers are the most willing to switch to a self-driving vehicle. This is 40 and 38 percent, respectively, for students and senior citizens but just over one in four for the working population. In general, people in employment make up the group most skeptical about the future use of autonomous mobility services. That said, many road users who previously traveled by public transportation, by bicycle or on foot would be willing to change their means of transportation. The number of trips made on foot or by bicycle would fall by 30 percent, while just over one in four users of public transportation would use a taxi or shuttle.

Fig. 5 – Willingness to switch to autonomous mobility services by age group and current form of transportation based on our online experiment (with 2,000 participants and corresponding waiting times and prices*)

Age group	Current form of transportation	Autonomous mobility service (total)	Autonomous taxi	Autonomous shuttle
People in employment	Car (driver/ passenger)	26%	15%	12%
People in employment	Foot/bicycle	24%	13%	11%
People in employment	Public transportation	23%	12%	11%
Senior citizens	Car (driver/ passenger)	38%	22%	17%
Senior citizens	Foot/bicycle	34%	19%	15%
Senior citizens	Public transportation	32%	18%	14%
Students	Car (driver/ passenger)	40%	25%	16%
Students	Foot/bicycle	36%	21%	14%
Students	Public transportation	34%	20%	14%

Source: Deloitte Research

* Note: This scenario assumes a maximum waiting time of ten minutes plus a price per kilometer of 34 cents for robotaxis and 15 cents for roboshuttles.

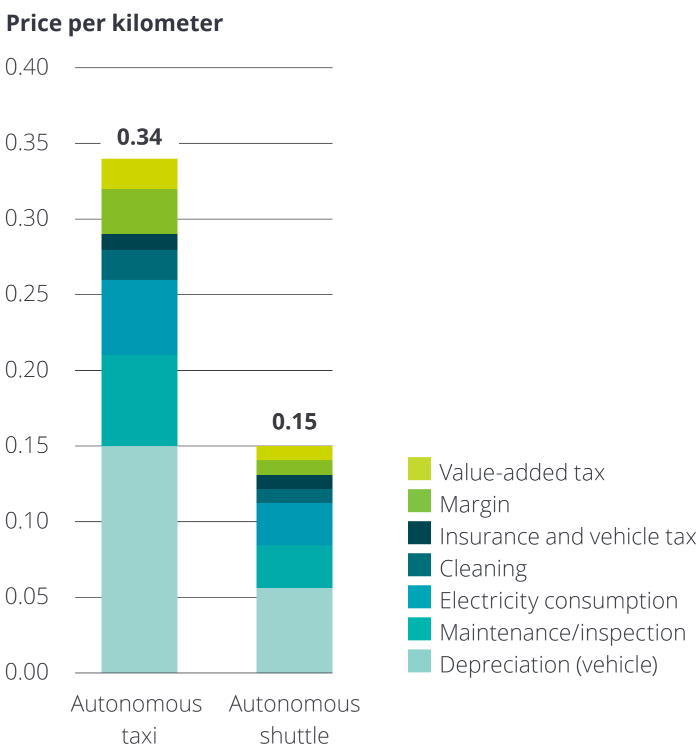


Assumption #2: Price war ignited – autonomous taxi and shuttle rides will be far cheaper than taking a private car or public transportation
When it comes to means of transportation, uptake depends crucially on the price. The demand outlined in assumption #1 can vary greatly depending on pricing. So, the crucial question is: how much is a taxi/shuttle ride expected to cost (calculated using appropriate methods)?

The following graph shows the price of one vehicle kilometer for an electronic autonomous taxi/shuttle (the exact data basis for the calculation can be found in the appendix). A standard industry profit margin for the operator has already been factored in.

Mileage in an autonomous taxi will be 25 percent cheaper than taking your own private car.

Fig. 6 – Composition of prices for one kilometer driven with an autonomous taxi/shuttle



Based on these specifications, the kilometer price for an autonomous taxi is expected to be 34 cents. This is only one-eighth of the price of a (conventional) taxi today (2.60 euros per km[4]) and 25 percent cheaper than taking your own mid-range car (VW Golf, 44 cents per km[5]) today. Parking costs for the private car are not included in this figure.

It is striking that depreciation and wear and tear make up around 40 percent of the fare, but that electricity consumption accounts for just 14 percent (autonomous taxi) or 19 percent (autonomous shuttle). Changes in the price of electricity for the vehicles therefore have only a marginal effect on the kilometer costs.

For the shuttle ride, we used a special route planner to determine more than 120 routes in German cities with two additional stops. This increases the total distance per user by approximately 50 percent and the total trip time by 65 percent (owing to detours and people getting on and off). However, as each trip takes an average of three people, the price per kilometer drops to 0.15 euros per passenger. A journey of more than 10 kilometers therefore costs just 1.50 euros. This is almost half the price of an average ticket for public transportation in German cities (2.80 euros) – even though the trip is door to door!

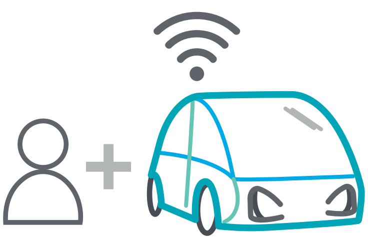
[4] Eurostat, http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=urb_ctran&lang=en, accessed on 14.08.2019.
[5] ADAC car cost calculator, https://www.adac.de/infotestrat/autodatenbank/autokosten/autokosten-rechner/default.aspx, accessed on 14.08.2019.

The prices clearly show that autonomous fleets pose serious competition for private cars and public transportation, making autonomous vehicles a likely choice for many people traveling to and from work and for shopping.

The price of electricity has only a marginal impact on the cost per kilometer.

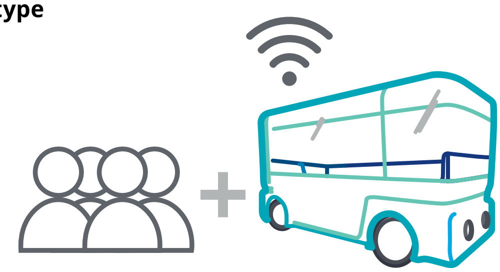
Fig. 7 – Central assumptions about the cost of autonomous taxis and shuttles

Electricity consumption by vehicle type



Autonomous taxi
(individual rides to a single destination for up to two people)

Electricity consumption
over 100 km:
18 kwh



Autonomous shuttle
(shared ride with different destinations and max. four passengers)

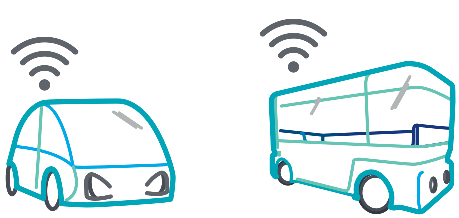
Electricity consumption
over 100 km:
25 kwh

Assumptions about the cost of purchasing and operating an autonomous fleet vehicle
Cost of the vehicle: 35,000 euros (25,000 for vehicle + 10,000 for technology)
Cost of electricity: 0.21 euros per kWh
Maintenance/inspection: 0.05 euros per km
Cleaning: 0.01 euros per km
Insurance & vehicle tax: 900 euros per year

Assumption #3: The market potential of autonomous mobility services is huge – if regulation allows

There are numerous opportunities on the horizon, not only for the users but also for the providers of autonomous fleet services. Our model estimates that people will take a total of 32.9 million trips per day, 18.8 million of which in an autonomous taxi. This will require a total of 560,000 autonomous taxis and 180,000 autonomous shuttles (740,000 vehicles in total) to accommodate these trips.

Fig. 8 – Calculated number of vehicles and trips taken per day in urban Germany in 2035



	Autonomous taxi	Autonomous shuttle	Total
Number	560,000 units	180,000 units	740,000 units
Trips per day	18.8 m.	14.1 m.	32.9 m.
Passengers per day & vehicle	34	79	44
Distance driven per day	348 km	373 km	354 km

The sales volume of the market for autonomous mobility services could amount to around 16.7 billion euros in 2035.

Over the average routes and prices, this will generate revenues of 59.5 million euros per day or 16.7 billion euros per year (with an average of 280 days in operation per year).

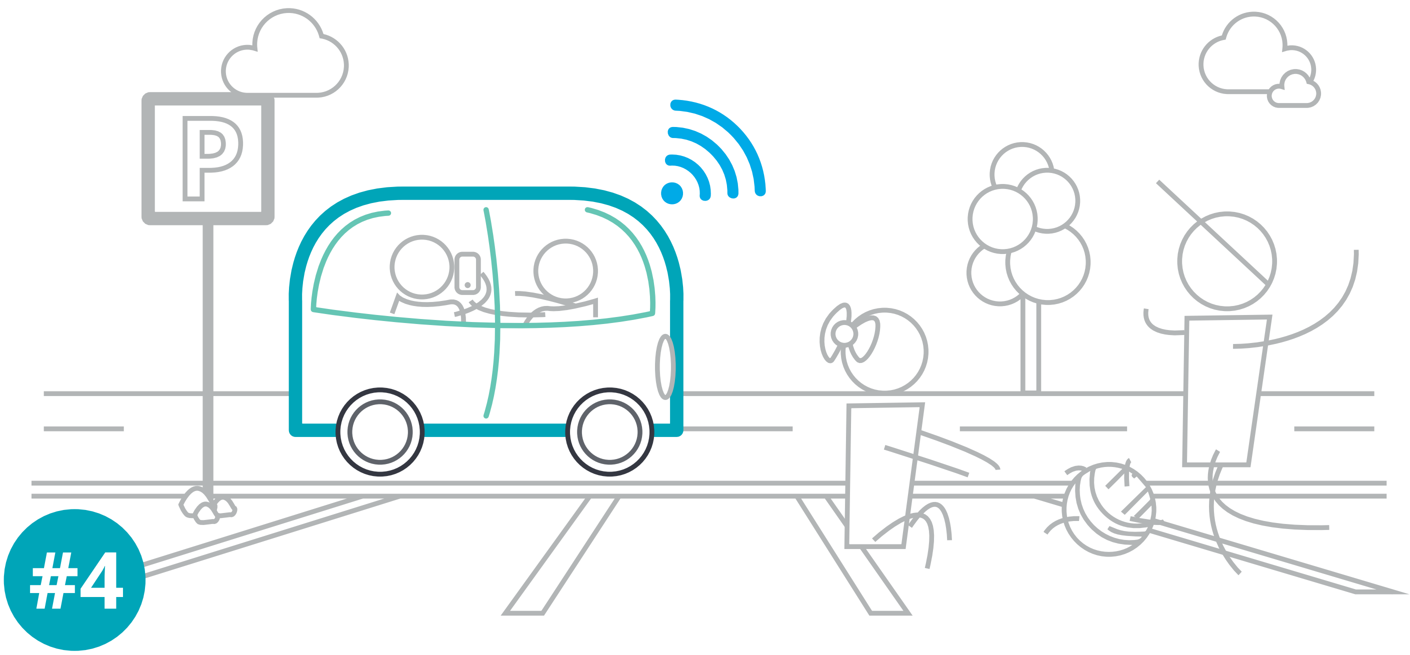
At the same time, the impact of autonomous mobility services on new car sales could be relatively minor. According to our calculations, the figure is expected to fall by just 25,000 units in our scenario. This represents a decline of just 0.7 percent[6] in the 3.3 million new car registrations per year in Germany. Since a new car currently costs roughly 30,250 euros on average, the decline in new car sales would decrease revenues by 760 million euros.[7] The additional revenue from the market for autonomous mobility services (16.7 billion euros) would therefore be many times higher.

Overall, our figures show that there is huge sales potential for suppliers of autonomous vehicle fleets, even without factoring in the revenue from auxiliary services and advertising displayed within the vehicles.

Market shift: the 760 million euro decline in sales is offset by potential sales of autonomous vehicle fleets amounting to 16.7 billion euros.

[6] Comment on the result: Since autonomous mobility services are only offered in urban areas in our scenario, the number of new car sales in rural regions remains unaffected and stable. The effect on new car purchases is therefore only evident in urban areas, which represent just one-third of Germany-wide sales figures (1.1 million new cars). Our consumer experiment showed that only around one-quarter of the 1.1 million new car buyers would opt out of car ownership if there were autonomous mobility services on offer (-265,000 new cars). However, the decline in sales is offset by purchases of new cars by autonomous mobility service operators. Due to the high utilization rate of the robotaxis and roboshuttles, one-third of the 740,000 fleet vehicles would have to be renewed (+240,000 new vehicles). The additional purchase of new cars by the operators of the autonomous mobility services thus almost compensates for the decline in private car purchases. On a net basis, the number of new car purchases will therefore fall by just 25,000 units.

[7] DAT Report 2018: Average price of new cars sold in Germany.



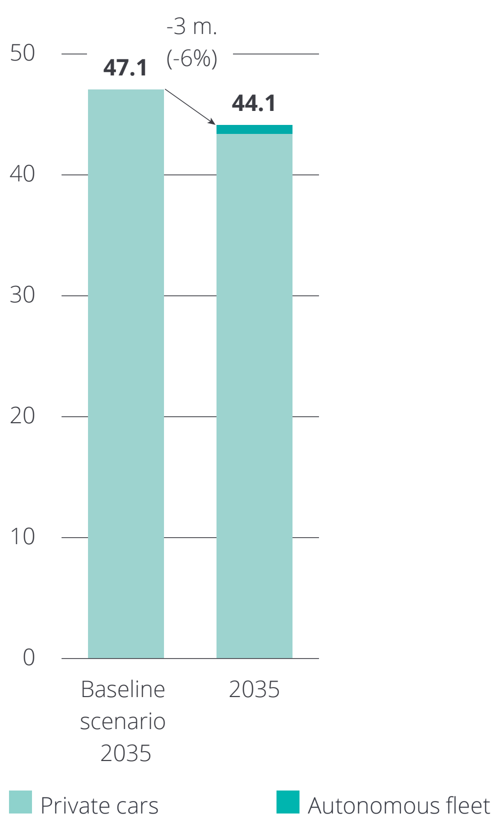
Assumption #4: Fewer vehicles – but more traffic in our cities

What will our roads be like in 2035? Although we will only see a marginal change in the number of new car registrations (see assumption 3), we expect a sharp increase in the use of existing vehicles.

At present, there are approximately 47.1 million passenger cars in Germany as a whole. Only one-third of these vehicles, around 15.6 million cars, are in use in the urban areas we studied. Our calculations estimate that the vehicle population will fall to 11.9 million (-25 percent), while an additional 0.74 million autonomous vehicles will be on the roads, resulting in a total of 12.6 million vehicles. That is 3 million or 20 percent fewer vehicles than today.

A reduction of 20 percent in the urban vehicle population will mainly ease pressure on parking spaces, freeing up prime urban real estate for other uses.

Fig. 9 – Population of passenger cars in Germany in 2035 including (baseline scenario) and excluding autonomous mobility services (in millions of cars)

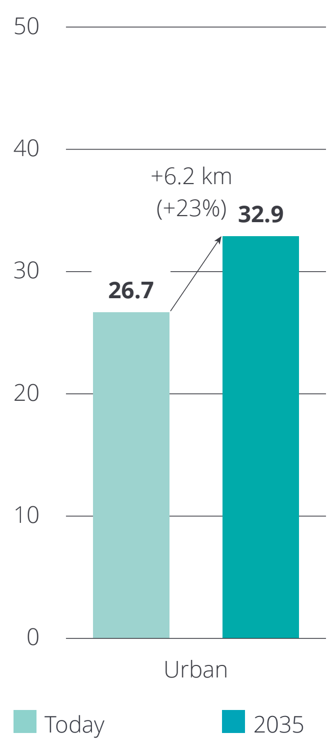


More kilometers driven per person per day

However, the decline in the number of registered vehicles does not allow any conclusions to be drawn about how many cars are on the roads at the same time. Because autonomous vehicles will have much higher utilization rates – even by people who use public transportation today or travel on foot or by bicycle – the overall number of trips will increase significantly.

Today, a person drives an average of 26.7 kilometers by car per day in urban areas, for both professional and personal trips. The new autonomous vehicle fleets will raise this figure to 32.9 kilometers per person per day in 2035, an increase of 23 percent.

Fig. 10 – No. of kilometers people travel by car per day in urban areas of Germany



30 percent more traffic due to cars driving at the same time

In addition, the number of vehicles on the roads at any one time will in fact increase by 30 percent. At first glance, this seems astonishing because of the decline in the number of registered cars, but the vehicles from the autonomous fleets will drive all day long, not just two or three trips like most private cars.

There are various reasons for this huge increase:

- Users of public transportation, cyclists, and pedestrians who are all part of the working population will switch to mobility services in large numbers, increasing the number of car journeys.
- Demographic groups like students (without a driver's license) and senior citizens (who are no longer willing or able to drive) will avail of autonomous mobility services.
- There will be a number of empty trips required to collect customers or to drive to charging stations.

This effect can already be observed today in New York, where additional, low-cost mobility services (ride hailing) have led to a significant increase in the number of trips taken per person.

Assumption #5: The risk of gridlock is growing – increased use of vehicles leads to an increase in congestion

The growing number of urban car journeys has consequences for the traffic load in Germany's cities. Our mobility model predicts that the increased demand for car journeys (autonomous fleet and private cars) will have two major effects:

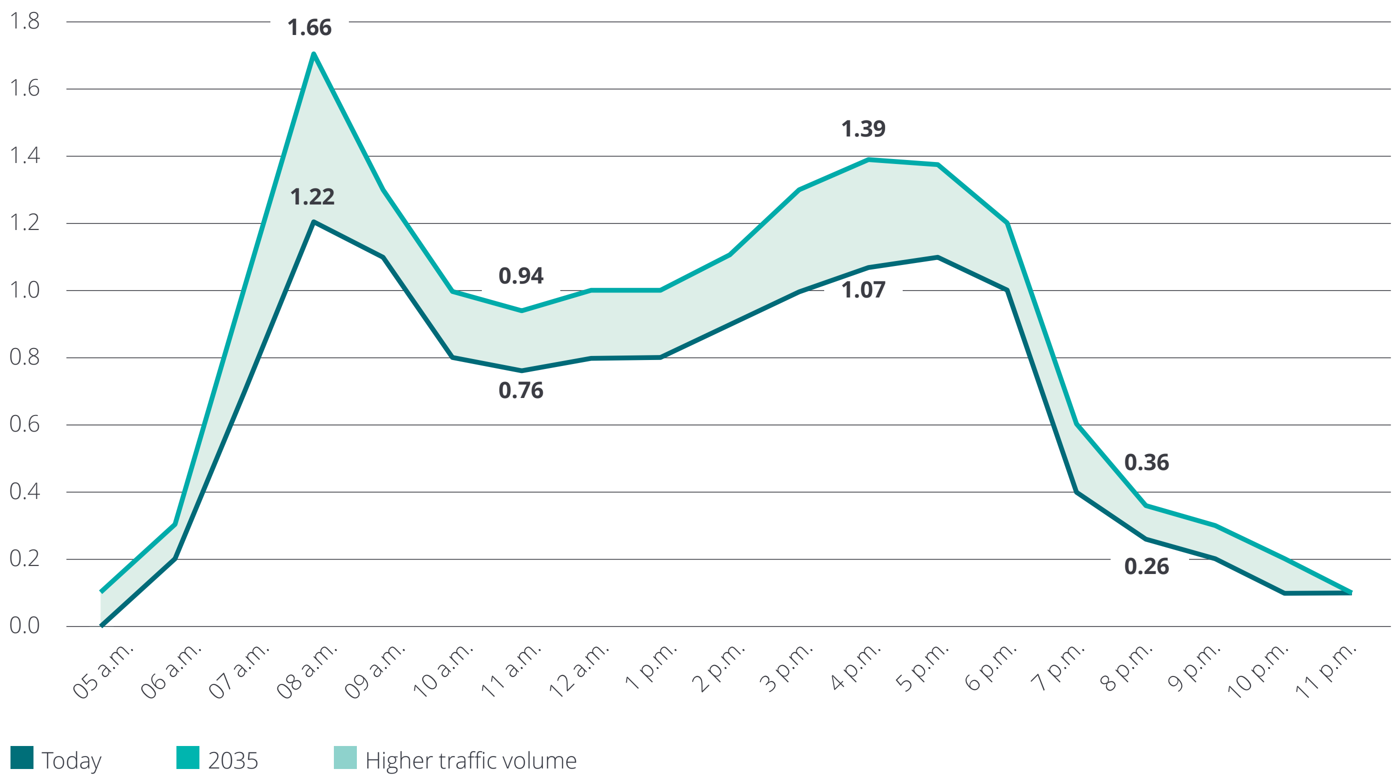
- The number of vehicles on the roads at the same time will increase.
- Traffic flow will decrease and the risk of congestion will increase significantly.

More congestion: on average, each trip will take 10 percent longer

More traffic will also lead to greater congestion and more traffic jams. We can assume that many non-autonomous vehicles will still be on the roads in 2035 and that improvements such as machine communication between vehicles (V2V) will not yet be fully effective.

At peak times (between 8:00 and 9:00 a.m.), traffic volume may increase by as much as 36 percent compared with today.

Fig. 11 – Drivers simultaneously on urban roads by time (in millions)



The increase in road traffic will take many city streets to the limit of their capacity and thus significantly slow down the flow of traffic. The average flow rate in the morning rush hour will fall from 33.5 km/h to approx. 30 km/h. A car journey will then take 10 percent longer, an average of 2.5 minutes more.

Users of autonomous fleet vehicles will probably find this even easier to tolerate because they can work or relax during the trip. For everyone else, it will increase the pressure to look for alternatives. We can only reverse this effect with a significant increase in the use of autonomous shuttles.

The shift from walking, cycling, and public transportation to autonomous mobility services will lead to more traffic, greater congestion, and longer travel times.

Effects: renaissance of the automobile

One of the main findings of our study shows that the use of large self-driving fleets is likely to increase the attractiveness of car and shuttle use for many people in urban areas. Seen in this light, it is clearly premature to start singing the swan song for the motoring age. In fact, the opposite appears to be true: new forms of mobility will give the automotive industry an opportunity to reinvent itself.

Opportunities for automakers and mobility providers

The sales potential in fleet services, which is quite considerable, can be further enhanced through optimization. We could, however, see a small number of players quickly dominate this market.

The number of new vehicle registrations in Germany is expected to decrease only slightly versus today. On the one hand, continuing urbanization and the availability of alternative transportation offerings, which may prompt many households to do without a second car, will lead to a decline in new registrations of private cars. Moreover, this trend will be reinforced by a decreasing status symbol effect.[8]

On the other hand, a sharp rise in the wear and tear of vehicles in autonomous fleet operation will shorten their useful life and require faster replacement (the total number of motorized kilometers in Germany will continue to increase as a result of autonomous mobility services). Based on the calculations and assumptions made for this study, these two effects will virtually offset one other.

In the future, providing passenger transportation services will therefore be more important than private car ownership. However, as long as the number of passenger kilometers traveled by motorized vehicles continues to increase, these developments will not only bring about significant changes in the value chain but also provide a wealth of opportunities for automakers.

[8] Deutsche Welle: Das Auto – Vom Statussymbol zum Nutzgegenstand, https://www.dw.com/de/das-auto-vom-statussymbol-zum-nutzgegenstand/a-38045277-0, accessed on 14.08.2019.

The market potential amounts to almost one-sixth of car sales in Germany

The market potential for autonomous mobility services is very lucrative, constituting a major new area of business for automakers and service providers with an estimated sales volume of 16.7 billion euros in 2035.

Fares for travel in self-driving vehicles will be significantly lower than the costs for private car use. This is mainly due to the much higher utilization rate of fleet vehicles compared with owning a car. Today, private cars are actually used less than 5 percent of the day, occupying a parking space for the remainder of the time. This generates increased costs – especially in urban areas where space is at a premium – and makes owning a car even less attractive, particularly for city dwellers.

Prices for autonomous mobility services are also likely to be attractive due to the falling acquisition costs for such vehicles. Economies of scale and technological developments in autonomous driving will drive down manufacturing costs over the coming years.

Competition will initially be fierce

The market for autonomous mobility services will be hotly contested. Besides traditional automakers, mobility providers such as car rental companies and new challengers from the technology sector will enter the market. It is not yet clear who will ultimately win the race.

In terms of market dynamics and competition, however, parallels from the ride-hailing business suggest that a "winner takes all" principle is emerging at the city level.

Whoever operates the largest fleet in an urban area can offer users the shortest average waiting times (customer satisfaction) and minimize the number of empty trips at the same time (cost leadership). Over the long term, only a small number of suppliers with corresponding economies of scale are therefore likely to prevail in fleet operations and dominate the market.

Private autonomous vehicles are a niche market

Aside from autonomous vehicle fleets, there will undoubtedly also be a niche market for privately owned autonomous vehicles. However, owing to higher acquisition costs over conventional cars, this segment will probably remain the preserve of a high net worth clientele, similar to today's premium class segment.

In the future, the distinguishing features in this segment are more likely to be comfort factors that allow passengers to relax or make good use of their time during the trip rather than features associated with driving pleasure today, such as engine power and acceleration. However, in this area as well we see numerous possibilities for automakers to set themselves apart from the competition as a brand.

What automakers should already be thinking about

We believe today's automakers would be well advised to start:

- focusing more on fleet operations and implementing the principle of mobility as a service (MaaS), both on their own and as a supplier to mobility providers. In any case, the total cost of ownership principle will become significantly more important in sales with fleet operators than in today's retail business.
- optimizing, with the goal of achieving attractive mileage prices, long useful lives, low maintenance costs, and the highest possible margins.
- thinking about how they can reposition their brand if vehicles become less a status symbol and more a means of transportation.
- considering the users of the fleets as customers for other services (for example, virtual reality experiences, travel guide mode) and as advertising targets.

Challenges for local authorities and policymakers

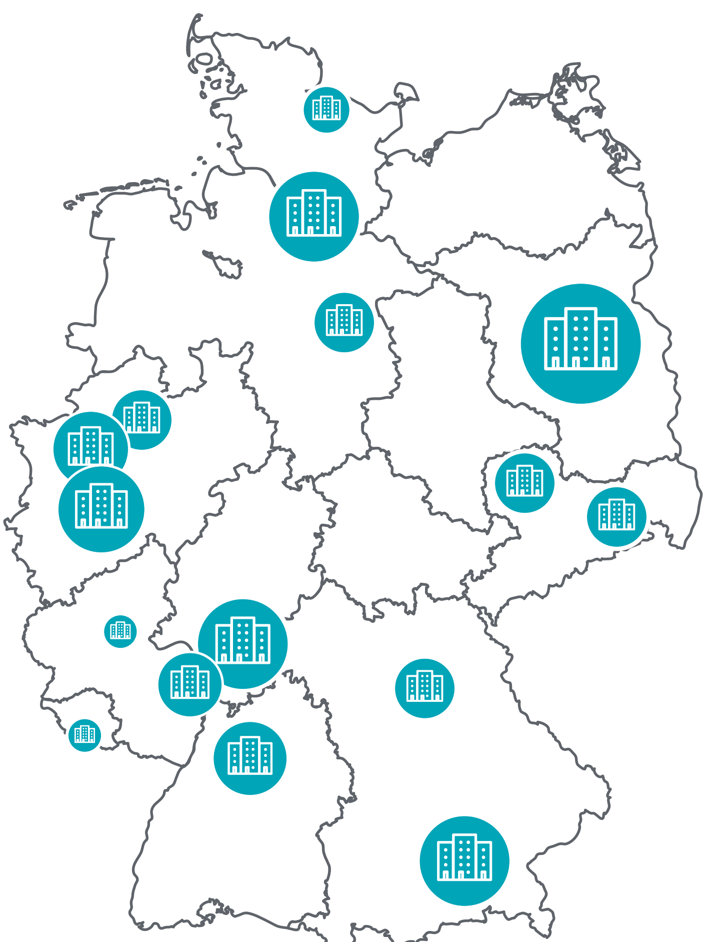
The increase in available parking space will be offset by a 30 percent increase in traffic. Public authorities need to clarify how they will respond to the change and whether they should intervene to regulate it.

Significantly fewer parking spaces will be needed

The results of the analysis show that the number of parking spaces needed will fall sharply by 2035 due to the 20 percent drop in city vehicle population. This free space could be used for additional cycle paths and sidewalks to actively support this movement. However, the availability of more free parking spaces in an urban area could also attract new traffic.

The 20 percent drop in the vehicle population will alleviate the shortage of parking spaces in cities and provide space for new uses.

Fig. 12 – Calculated number of vehicles used for autonomous mobility services per city in 2035



City	Autonomous vehicles
Berlin	95,000
Munich	55,000
Hamburg	47,000
Frankfurt/Main	41,000
Cologne	33,000
Düsseldorf	23,000
Stuttgart	22,000
Mannheim	19,000
Nuremberg	15,000
Dresden	13,000
Leipzig	12,000
Hanover	12,000
Münster	7,000
Kiel	7,000
Saarbrücken	4,000
Koblenz	4,000

Increasing traffic calls for smart regulation
Our study also shows, however, that cities and local authorities cannot expect autonomous mobility services to reduce traffic congestion. In fact, precisely the opposite could happen. Without stimulus or other intervention, use of public transportation is likely to decline. Similarly, the number of pedestrians and cyclists will decrease, while the use of cars will increase.

To avoid impending gridlock, it may therefore be necessary to regulate driving in urban areas not only for environmental reasons, but also to improve traffic flow. Rather than focusing on simply on limiting the size of the autonomous vehicle fleet, however, regulations should try and come up with a smart approach that factors in all of the interactions between all stakeholders and all transportation offerings, aiming to achieve the best possible combination of mobility offerings.

If this intervention is successful, the benefits of autonomous mobility services – in terms of flexible, low-cost, efficient use of vehicles – could add real value for urban mobility and connectivity. By integrating autonomous mobility services in a way that focuses on their benefits, cities could transport their population more efficiently and cost-effectively over the long term and increase their urban appeal in the process.

It is up to our local authorities and cities to start working today to develop the ideas and measures that will keep traffic flowing in the city of the future. Smart regulation could be a solution.

Outlook

The results of our study show that self-driving taxis and shuttles will have far-reaching effects on urban life in 2035. The advantages of autonomous mobility services are obvious: fast, cost-effective, individual mobility for all residents at any time of the day.

We do not believe that autonomous mobility services will cause private car ownership or public transportation to disappear, but instead will create a new, ancillary market for mobility and growth in the transportation industry as a whole. Urban populations will therefore have greater choice in terms of the means of transportation available to them and will be able to choose based on their needs.

For automakers, the results of our study are good news. We have shown that autonomous mobility services will lead to an increase in car-based journeys, though they are not likely to significantly decrease new car purchases. Nevertheless, the auto industry will have to initiate sweeping change and face numerous risks in addition to these growth opportunities. If automakers evolve into mobility service providers, shifting the customer focus away from the brand of the vehicle and more to the trip itself, we could see an increase in sales potential, even as competition with direct rivals and competitors from outside the industry intensifies.

Cities and local authorities are already concerned about the impact of daily traffic on their roads. The results of our modelling show that traffic could increase further with the introduction of autonomous mobility services. Cities should therefore already start developing concepts for the optimum integration of autonomous, electric powered vehicles and mobility services into the urban traffic space and promoting and expanding existing means of transportation. Success in this area could enable the municipality in question to sustain or even increase its quality of life and urban appeal, which in turn may generate decisive advantages in the competition for residents and commercial entities.

Our analysis marks the first study of its kind to provide a valid perspective for the future of mobility in Germany as a whole. It provides business decision-makers, policy-makers, and local authorities with a realistic picture of mobility in the year 2035, providing food for thought as they consider options for future action.

Appendix: Methodology and data bases

The following sections contain detailed descriptions of the data basis and methodology of our study. In them, we reveal the sources and calculations that form the basis and the assumptions that were made in our modelling.

Data basis
The data used for the study dates from 2017 to 2019. The data bases were the study entitled "Mobility in Germany 2017" by the Federal Ministry of Transport and Digital Infrastructure, alongside data from the OECD, the Federal Statistics Office, Eurostat, the TomTom Traffic Index, and Germany's ADAC automobile association.

Basic assumptions
Basic assumptions for the calculation of the autonomous vehicle fleets in 2035 were:

- Vehicles can be ordered very easily via app, using voice instructions or based on artificial intelligence.
- The maximum waiting time for a vehicle is ten minutes.
- Passengers are transported from door to door.
- The autonomous vehicles are all battery-operated electric cars.

If vehicle sharing is to be commercially successful, a minimum mobile population is needed. This network effect ensures that

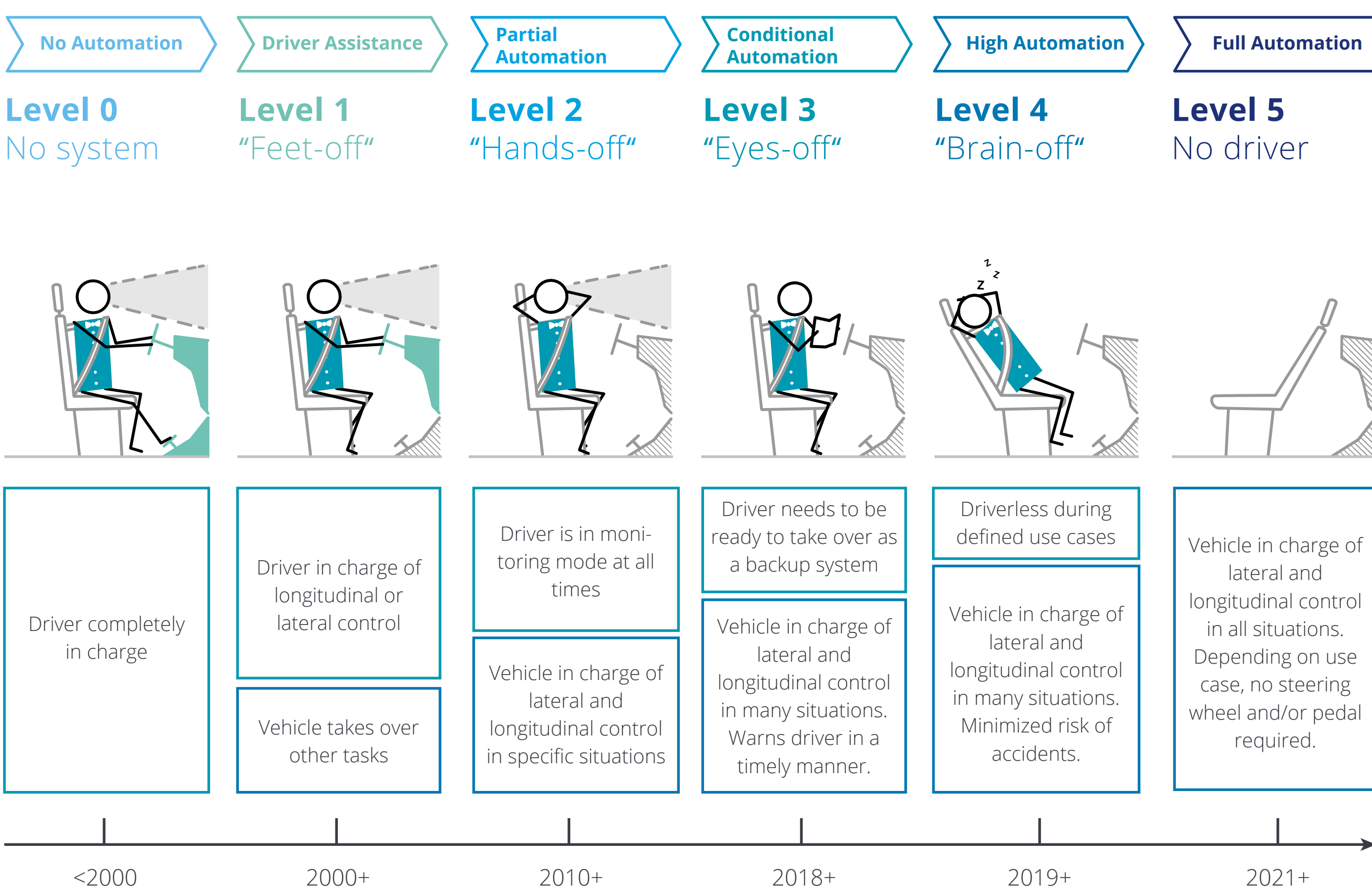
- a vehicle is available shortly after being requested (this only works with a large number of vehicles within a small area),
- a high utilization rate is achieved, which is necessary for cost-effective operation,
- there are always enough free vehicles available.

Only if these conditions are met will the service be accepted and work.

Definition of autonomous vehicles
The basis for the analysis is a completely autonomous vehicle. The automotive industry has developed a model comprising six levels of automation (level 0 to level 5). In levels 0 to 2, there are no or few assistance systems that assist the driver while driving. In level 3, the vehicle can drive autonomously, but the driver needs to be ready to take over again at any time. Such systems already exist or are close to market maturity.

Levels 4 and 5 describe systems that can operate completely autonomously. In level 4, a person can still take control, whereas in level 5 this is no longer possible; these vehicles have neither a steering wheel nor pedals. Level 5 vehicles form the basis of this study.

Fig. 13 – Development levels of self-driving technology



Source: Deloitte: Autonomous Driving: Hype or Reality? 2019

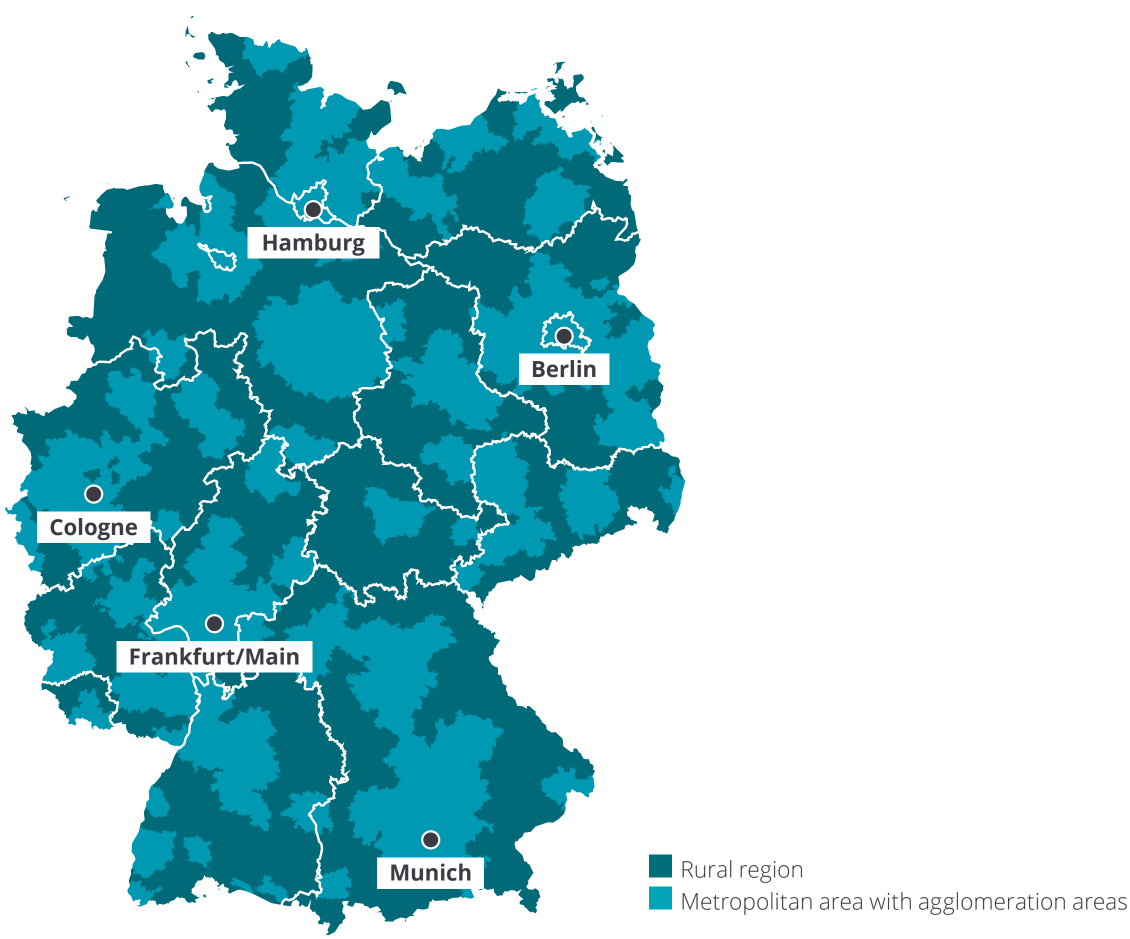
Metropolitan areas as core areas of autonomous mobility services

As previous chapters of the study have clearly illustrated, a core assumption of our study is that autonomous mobility services will be concentrated in urban centers and their densely populated areas. Densely populated areas with correspondingly high utilization rates of vehicles are necessary to guarantee cost-effectiveness and benefits for users. An OECD database that identifies Germany's metropolitan areas was used to determine the suitable areas for our study. They were then analyzed in detail and broken down into their individual zip code areas in order to define the core areas of autonomous mobility services within the metropolitan region.

There are 109 cities and metropolitan areas in Germany, each with at least 50,000 inhabitants. The map shows the allocation of rural regions (dark) and metropolitan areas (light).

In most cases, the agglomeration areas on the fringes of large cities, from which employees commute to the core every day, are not densely populated enough to justify operating a fleet of vehicles there. For the study, we identified the core areas with a sufficient number of people for autonomous mobility services by dividing these greater suburban areas by zip code and performing a precise analysis of population density and commuter flows. If these core areas included zones that do not meet the criteria but are considered transit areas for daily commuters, we also added them to the core areas.

Fig. 14 – Germany's metropolitan areas according to the OECD classification



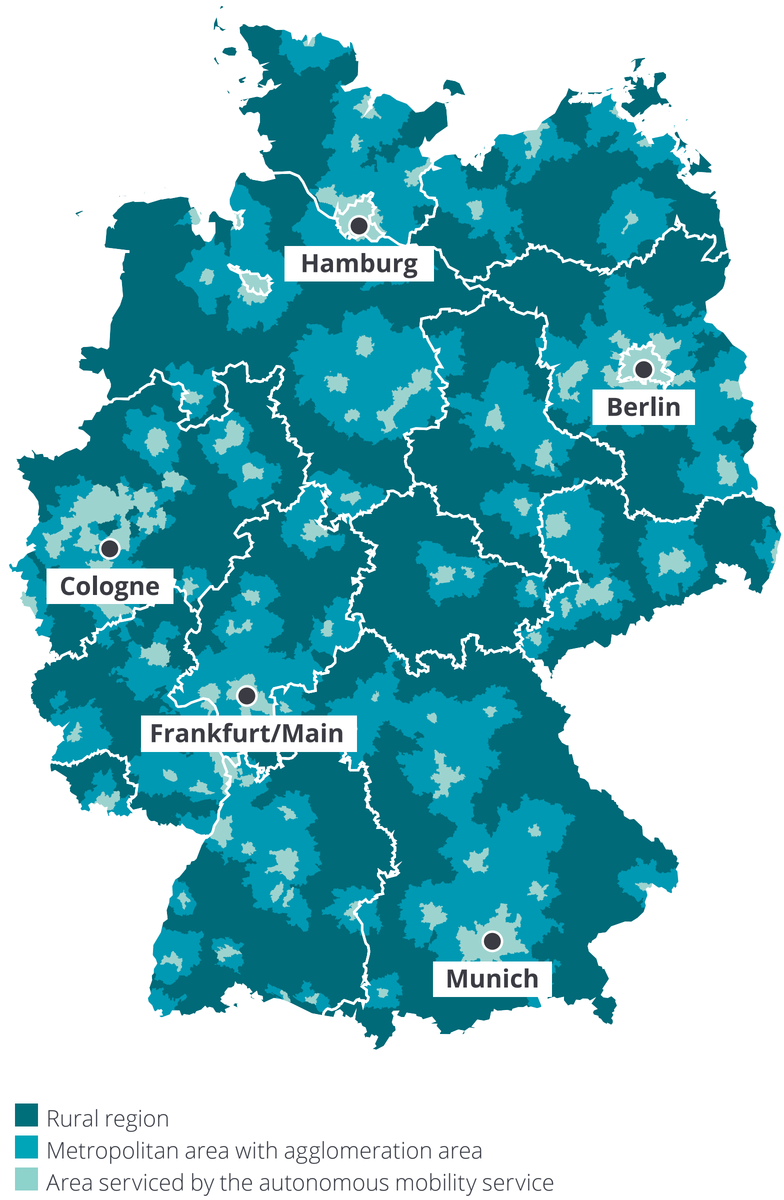
City	Metropolitan area (km²)	Area with AMS[9] (km²)	Share of metropolitan area with AMS
Berlin	8,970	2,180	24%
Munich	6,460	1,650	26%
Hamburg	6,330	1,340	21%
Frankfurt/Main	4,060	740	18%
Cologne	1,960	550	28%
Düsseldorf	1,230	420	34%
Stuttgart	1,930	390	20%
Mannheim	1,970	660	34%
Nuremberg	3,350	420	13%
Dresden	2,660	390	15%
Leipzig	2,820	330	12%
Hanover	3,220	210	7%
Münster	1,740	310	18%
Kiel	1,990	210	11%
Saarbrücken	950	220	23%
Koblenz	1,490	320	21%

[9] AMS – autonomous mobility services

A precise analysis of the population density reveals 109 service areas in which 40 percent of the German population live. However, these areas account for only 7 percent of the total area of the Federal Republic of Germany. This shows the high population density and large number of potential customers in a relatively small area.

These areas are bright green on the map. It is clear that they often extend beyond the core inner city area, because of the very high share of commuters in the densely populated affluent exurbs of large cities in particular.

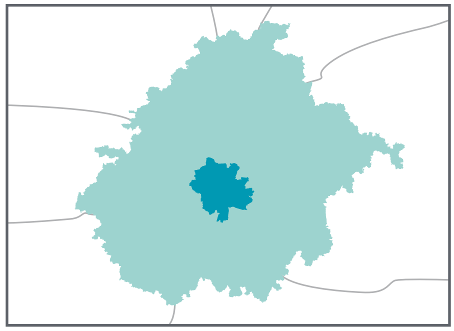
Fig. 15 – Areas suitable for the operation of autonomous fleets



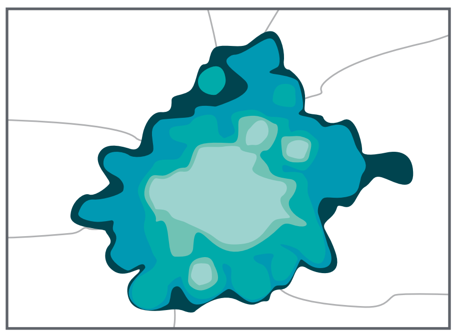
In Germany's core metropolitan areas, 40 percent of the population live on 7 percent of the area.

Fig. 16 – Allocation of autonomous mobility service areas using Munich as an example

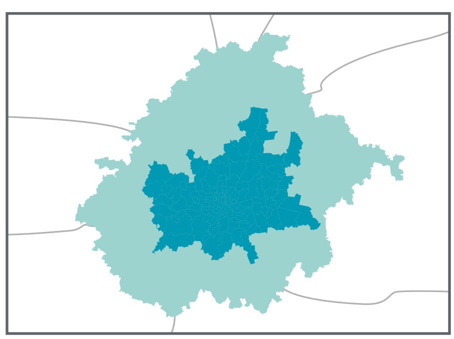
A good example of this is the Munich area. The core area ("City of Munich") is relatively small, but the urban agglomeration area (i.e., commuter towns) is much bigger.



If, on the other hand, we consider the population figures for the entire region, the picture changes dramatically. The suburbs and neighboring communities (such as Garching, Unterschleißheim, and Wolfratshausen) also have a similarly high population density and commuter rate to the city center.



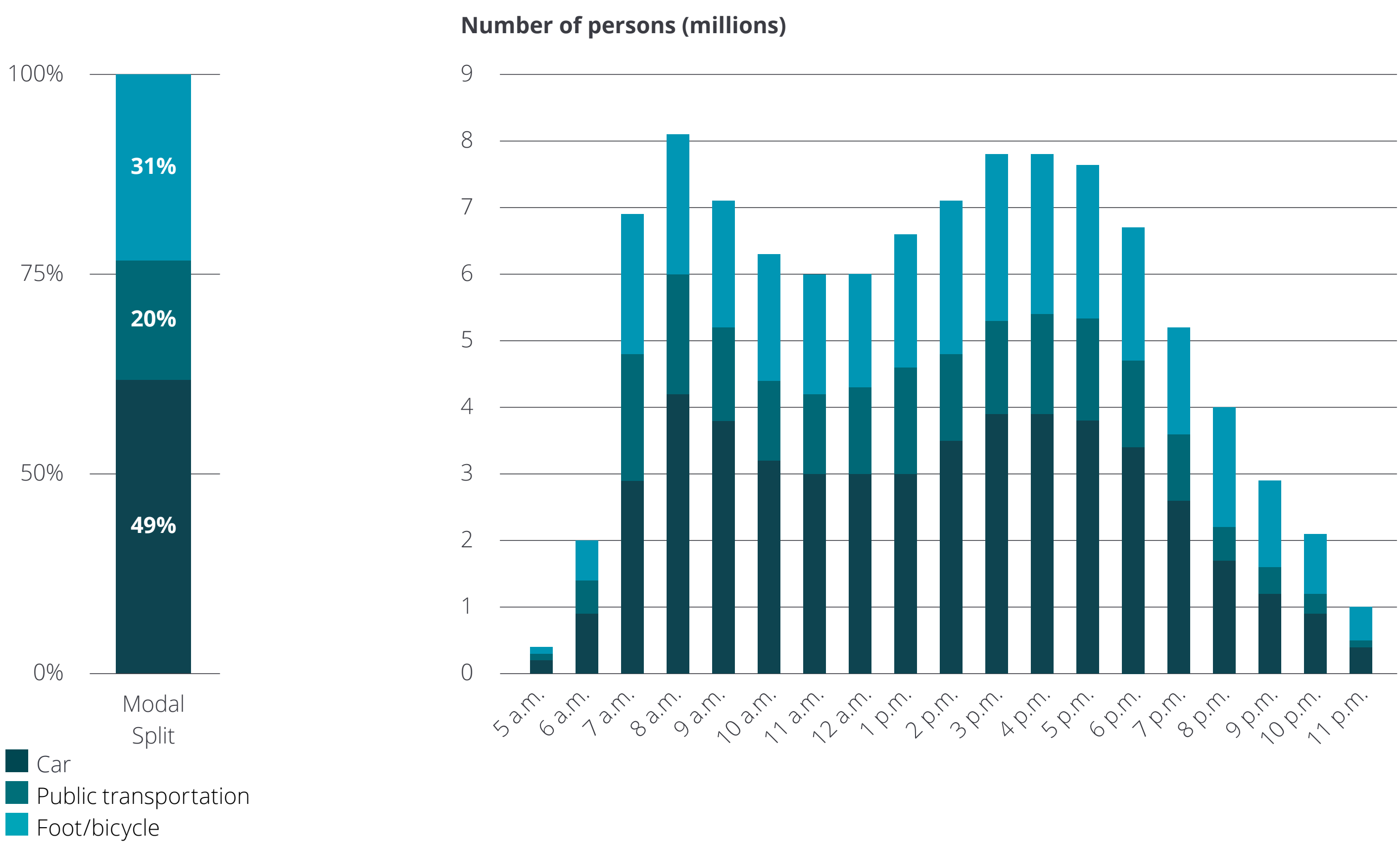
Since the areas between the city center and the densely populated peripheral areas (the "transit area") are also suitable for operation of an autonomous vehicle fleet, we have added these areas to the service area. This gives an area that is around five times larger than the core.



Mobility patterns in urban areas
To calculate future autonomous vehicle fleets in 2035, it is important to know how and when people move around today. If a certain percentage of these switch to autonomous vehicles in the future, it will be possible to determine how large these fleets need to be to meet demand.

Car traffic accounts for almost half of weekday mobility in German cities (49 percent). At 31 percent, cyclists and pedestrians make up the second-largest group. Public transportation transports only one-fifth of all people.

Fig. 17 – Current modal split and mobile persons (in millions) by time in Germany's urban areas



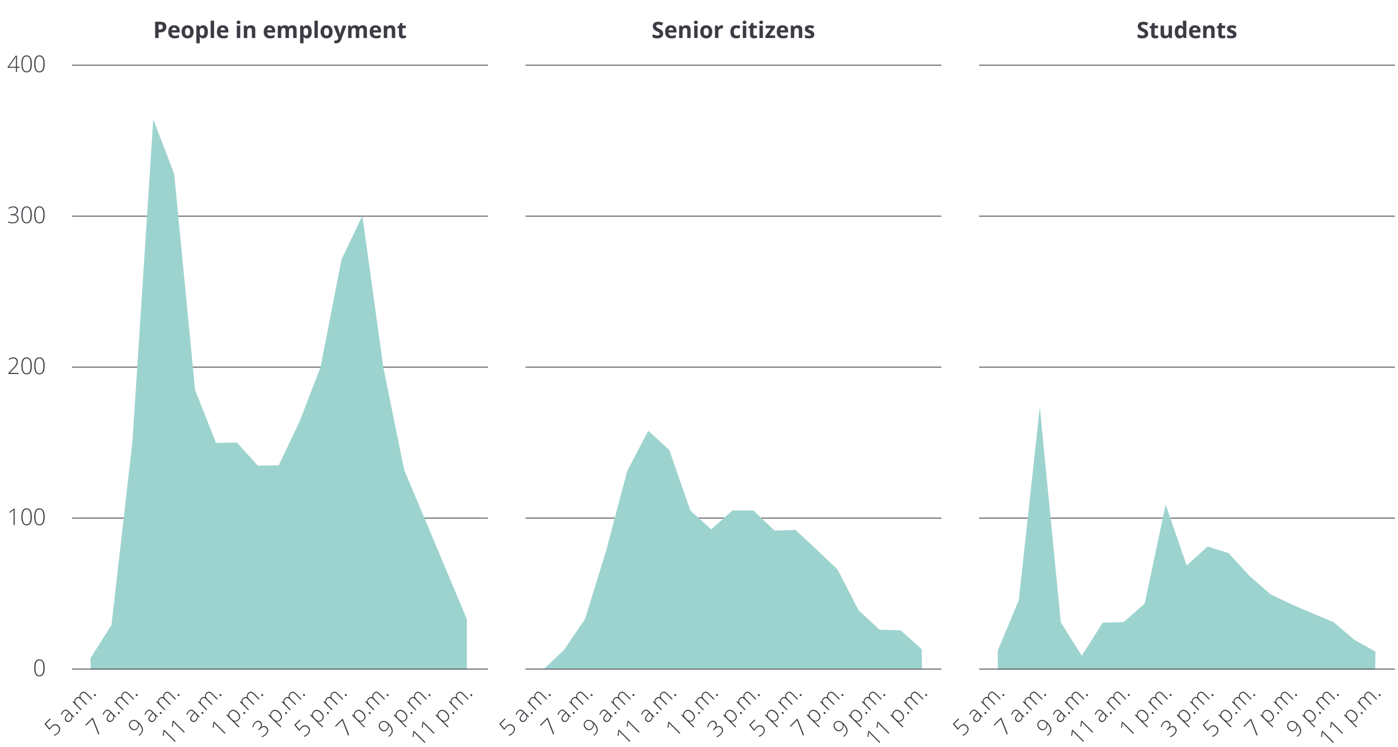
There are clear load peaks throughout the day. On a working day between 7:00 a.m. and 9:00 a.m., for example, a particularly large number of people are on the move. The typical after-work traffic starts at 3 p.m. and does not decrease significantly until 6 p.m. At peak times, more than 50 percent of all people use their car.

When planning fleet sizes, it is also important to remember that willingness to wait for a vehicle is rather low during peak times. A vehicle fleet must therefore be designed for peak load times in order to increase uptake among users.

Generational differences
There are clear differences in mobility between different age groups. People in employment are mainly on the road in the mornings and evenings, while school students have to make the most trips in the mornings and at lunchtime. Senior citizens, on the other hand, often move around in the morning, with a clear peak between 10:00 and 11:00 a.m.

Students and senior citizens are the age groups that we found mainly traveled on foot, by bicycle, and by public transportation up to now. This can and will change significantly with the introduction of autonomous vehicles.

Fig. 18 – Mobile persons by age group and time in the Munich base case (in thousands)



At peak times, 8 million people are on the move in German cities.

Price calculation
The calculation of kilometer prices for autonomous taxis and shuttles assumes that the prices for electric cars will fall significantly. We have assumed a price of 25,000 euros for the vehicle itself, plus 10,000 euros for autonomous driving technology.

Further relevant information for pricing:

- Autonomous taxis consume approx. 18 kWh of electricity per 100 km, autonomous shuttles 22 kWh.
- The commercial electricity price for 1 kWh is 0.21 euros, which corresponds to current prices for 2019.
- Maintenance, inspection, and cleaning are estimated at 5 cents/km.
- For each trip the autonomous taxi adds 2.3 km for the empty trip, the autonomous shuttle just 0.9 km.
- A vehicle puts 300,000 km on the clock before being replaced.
- For each kilometer, the operator adds a standard profit margin corresponding to the margins of premium manufacturers in the leasing business.
- VAT is estimated at 7 percent (as usual for taxis).
- Insurance and tax on the vehicles cost 900 euros per year.
- For the shuttle, we assume that an average of three but a maximum of four people will be transported.

For the additional distances and travel times of a shuttle, 120 arbitrary shuttle routes were created using the GraphHopper Directions API, which include two additional stops. The shuttle routes pass through the centers of four adjacent zip code areas. A comparison with the direct connection from start to finish gives a 50 percent longer distance and a 65 percent longer driving time.

As with all prices, we assume the same level of purchasing power as in 2019. To make the model calculation easier to compare, we have not made any inflation adjustments for 2035.

Mobility patterns and online experiment
To determine the choice of means of transportation, we conducted an online experiment with 2,000 participants using the stated preference approach. Participants had to imagine an everyday scenario (work, leisure time) in which they needed to travel a certain distance. They could choose from various means of transportation with relevant conditions (price, waiting time and route, including autonomous vehicles). The conditions and situations were varied between respondents so as to identify behavioral changes.

The result was a model capable of calculating the demand for autonomous fleet vehicles under different conditions.

Here, too, the data basis was the study entitled "Mobility in Germany 2017," which found that every person in the service area travels an average of three journeys per day. It was also possible to determine the number of trips for each hour of a day.

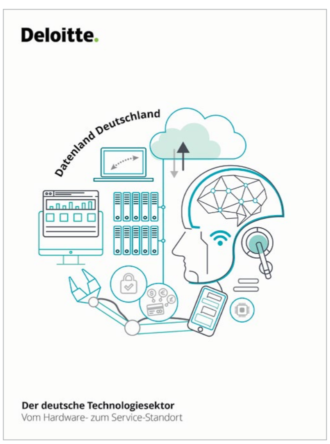
Derivation and calculation of all other data
Using the data from the study and the survey, all remaining data of the study can be derived. This includes:

- Change in the use of means of transportation for different times of the day and demographic groups
- Average number of kilometers traveled per day, per trip, and per person and thus the higher traffic load in 2035
- Minimum number of fleet vehicles needed to maintain a maximum waiting time of ten minutes even at peak times
- Useful life of fleet vehicles with an assumed mileage of 300,000 kilometers
- Calculation of sales revenue per day and per year based on the number of kilometers traveled per day
- Changes in the number of vehicles and the average trip duration

Further basic assumptions of the calculations
One of the basic assumptions in this approach is that the mobility needs of people in 2035 are not significantly different from those in 2019. In addition, we have not included an inflation factor: The prices for trips in 2035 correspond to purchasing power in 2019 – this makes it easier to make comparisons with today.

An online experiment with over 2,000 participants in Germany shows how strong demand is for autonomous taxis and shuttles and in which day-to-day situations city residents would use these new mobility services.

Previous studies in the "Data Nation Germany" series



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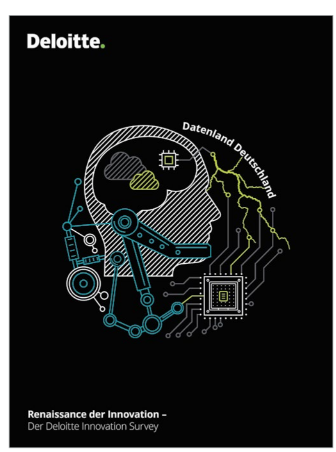

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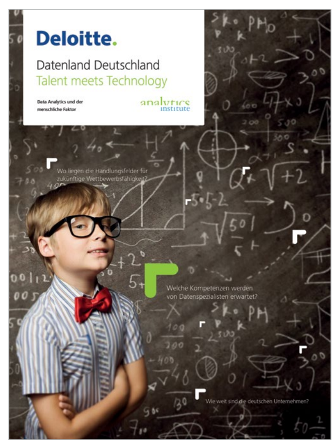

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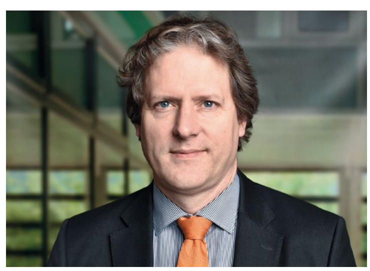

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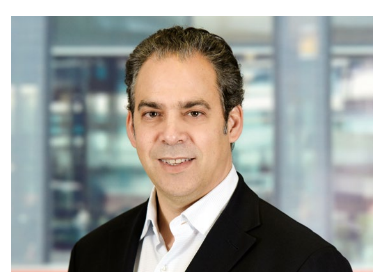

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