Autonomous Driving
Expectations of future mobility
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1 Summary
Introduction

Autonomous driving was once just science fiction; now it is one of the most exciting technological developments and a core driver of mobility. Thanks to the astounding technological progress in recent years it is increasingly becoming reality: many vehicle manufacturers are putting huge resources into the development of automated and autonomous vehicles. Self-driving vehicles that can be used for any purpose and in any environment do not yet exist, but the essential technologies to achieve this are in principle already available. Field testing areas that approach real conditions enable further development, also in Germany. On the political level the preconditions for autonomous driving are already being prepared. The necessary legal framework is being developed nationally and internationally.

Autonomous driving is not only an opportunity for vehicle manufacturers; it will also revolutionise the services offered by professional providers of taxis, hired cars and car sharing services. Self-driving vehicles will support the development of mobility as a service and will result in profound, long-term changes in the mobility market, above all in city traffic. The significance of the private car will diminish in the face of potentially attractive, comprehensive and probably cheap mobility provision. The new technology will also open up new opportunities to reshape public transport in a more efficient, intelligent way.

Autonomous driving is undoubtedly an interdisciplinary topic. Developing autonomous vehicles demands close collaboration between vehicle manufacturers, component suppliers and IT companies. It also requires forward-looking policies and public authorities that provide efficient traffic management, intelligent infrastructure development and urban planning vision. The topic of autonomous driving is increasingly under discussion in companies and public authorities and is the subject of numerous conferences.

In this paper we provide a comprehensive overview of the expectations currently placed in this technology. We have surveyed experts and responsible persons in municipalities, vehicle manufacturers and component suppliers (also referred to in the following by the abbreviation OEM: original equipment manufacturer), public transport companies and private mobility service providers to gain insights into their current perception of autonomous driving. Based on this wide range of opinion we derive possible developments and relevant options for action. The study includes numerous diagrams that present evaluations of the survey. To make it easier to understand the diagrams, the groups to which we addressed specific questions are identified by symbols in the study, shown in Fig. 1.

<table>
<thead>
<tr>
<th>Group</th>
<th>Mobility service providers</th>
<th>Public transport companies</th>
<th>Municipalities</th>
<th>Vehicle manufacturers and component suppliers</th>
</tr>
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<tr>
<td>Symbol</td>
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</tr>
<tr>
<td>Abbreviation</td>
<td>MOBSP</td>
<td>PTC</td>
<td>Municipalities</td>
<td>OEM</td>
</tr>
</tbody>
</table>

Fig. 1: Symbols and abbreviations referring to surveyed groups
New opportunities for the vehicle manufacturing industry, mobility services, public transport and municipalities

Most respondents see autonomous driving as an opportunity rather than a risk (see Fig. 2). Looking at the mean values of the answers, mobility providers are particularly optimistic. They anticipate a wide range of new opportunities in autonomous driving and predominantly identify advantages for new business models.

Vehicle manufacturers and component suppliers also primarily see opportunities for the industry. A new type of vehicle will emerge, resulting in new sales markets. The challenge lies in not being left behind in the race to develop an autonomous vehicle.

Many of the public transport companies surveyed also reveal great optimism. The technology could have a number of positive effects for public transport applications. Those in management, however, also fear possible competition by individual autonomous mobility services.

The municipalities are comparatively sceptical, as revealed for instance by the relatively large number of ‘neutral’ responses. There are fears that autonomous driving will entail new demands for the municipalities that will compete with a range of current topics. In this context the respondents mention electric mobility, cycling infrastructure and intelligent traffic management, all of which currently enjoy higher priority. Despite this, municipalities do recognise that the new technology offers opportunities, but it is still difficult at this stage to estimate the actual impacts on cities.

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**Fig. 2: Autonomous driving – opportunity or risk?**

**Mobility service providers**
- Car-hire companies, car sharing providers, internet platforms, taxi services
  - Very interested in self-driving vehicles to improve services
  - No negative expectations

**Vehicle manufacturers and component suppliers**
- Producers of autonomous vehicles and component suppliers
  - Market potential of autonomous vehicles
  - Possible competition, above all from the IT industry

**Public transport companies**
- Biggest public transport companies in cities with over 100,000 inhabitants
  - Collective mobility providers
  - Driverless vehicles to improve services
  - Competition, mainly by individual service providers

**Municipalities**
- Public authorities in cities with over 100,000 inhabitants
  - Provision of infrastructure and legal conditions
  - More diverse transport system for the population
  - Concerned about additional investment and traffic congestion

Source: DCI
Almost all respondents consider autonomous driving to be technologically feasible and expect the idea to become reality in the future. Vehicle manufacturers and suppliers anticipate that the first vehicles will be ready to go into mass production by 2025. Potential users, the public transport companies and mobility service providers, are more optimistic, anticipating that vehicles will already be available by 2020. This shows the market’s high level of interest in this technology. All respondents agree that the advantages of autonomous driving will be so great that self-driving vehicles will be standard by 2050.

The development of autonomous driving is already widely anticipated, so market participants can adjust their positions in good time. This certainly makes it possible to steer certain technological developments and to exert influence at an early stage on application types. On the other hand, a great deal of market movement is to be expected as soon as the first driverless vehicle is available. Preparations for autonomous driving are already under way. This development is central for manufacturers and suppliers, but mobility service providers have also already positioned themselves accordingly. Public transport companies are still rather more cautious, but are also extremely interested in the technology and in early pilot projects.

Many respondents in the municipalities can envisage pushing ahead with concepts for autonomous driving. Many municipalities where manufacturers or suppliers are located are collaborating with the companies to develop field testing areas to test technologies. They are also interested in supporting public transport or sharing models, to promote the advantageous development of autonomous driving. These concepts will be put into practice as soon as suitable vehicles are available.

Driverless vehicles will become part of the digital networked world. That applies equally to all vehicle-related services from maintenance and new mobility services to digital maps and navigation. Not only manufacturers and suppliers need to prepare themselves for these developments; mobility service providers and public transport companies must also take steps. The municipalities must also develop comprehensive competencies in order to understand autonomous driving and to influence it in the long term.

Mobility becomes a service

Autonomous driving services will combine the advantages of taxis, car sharing and public transport. Trips could start directly from peoples’ front doors and could be ordered on the spur of the moment. At the same time, passengers could use the time in the vehicle for other activities. Autonomous vehicles will not require drivers and could be used in a very flexible way. Services could be dynamically and cheaply adjusted to demand using autonomous vehicle disposition. Robo-taxi services with self-driving vehicles will be extremely appealing and will attract new customers.

As soon as driverless vehicles are in use, the current provision of taxis, hired cars and car sharing will become more similar to each other. One significant new form of provision will be shuttle services that constitute a kind of cross between individual and collective forms of transport by which several people are transported at the same time but independently of timetables and routes. This will create additional overlaps with public transport. Both mobility service providers and public transport companies anticipate a significant market for transport of this kind.

Because there are no added costs for drivers, robo-taxi services could be cheap, yet still cover costs. Competition between several rival providers, potentially high utilization of vehicles and additional services provided during the journey will ensure that these services can be offered cheaply overall. We may assume that these transport services will be able to cover their costs. Public transport companies anticipate that they will be able to significantly improve their service provision and attract new customers. At the same time however they fear the competition of individual robo-taxi services.
These mobility services need not be restricted to cities; they could also be provided in the country and for long-distance routes. Different types of provision could be offered, with specific types of vehicles available to cover every need. In the long term this would result in the comprehensive and reliable availability of vehicles, so that in many cases it will no longer be necessary to own a private car.

Vehicles and vehicle manufacturers are changing

Vehicle manufacturers will be forced to offer self-driving vehicles in order to survive in the mass market in the long term. Because a very rapid and strong demand for driverless vehicles is anticipated, the manufacturer who provides the first mass-production vehicles will gain a serious advantage over rivals. Manufacturers and component suppliers assume that the first permits for autonomous vehicles are more likely to be issued in the USA or China rather than in Germany or Europe. Therefore the main push of their development efforts should also and initially be in those countries, oriented on the specific local conditions. On the other hand, they must also be prepared for conditions in the other countries.

Comprehensive IT competence will be essential for the development of autonomous vehicles. Current systems development processes and the necessary tests cannot cover anywhere near all demand. It is anticipated that IT components will comprise 50 percent of a car’s total added value; it will be just as essential for the vehicle’s function as the power transmission, for example, is today. In future, autonomous driving functions and the software and sensor technology required for them will be a significant unique selling point for the vehicles. Manufacturers that fail to build up their own expertise will dwindle in the long term to become suppliers of vehicle parts. The division of functions between vehicle manufacturers and today’s suppliers may change depending on who develops the new IT components.

The driving license will become irrelevant in many cases. Engine capacity will no longer be particularly important to most users. The important aspects of driverless vehicles will be comfort features, digital equipment and vehicle networking. At the same time the need for flexible interfaces with passengers will increase. The assumption is that autonomous vehicles will drive more safely than human drivers. For this reason, sensor technology and monitoring the environment will become more important than all-round visibility and passive safety elements. In the end cars could become smaller and lighter. It will also be much easier to organise electric drive systems for autonomous vehicles: cars that are part of a fleet can be withdrawn from service regularly to charge their batteries. Vehicles of this type might be used successfully in cities with small batteries and frequent charging periods.

Mobility service providers will become much more important customers for manufacturers. For this reason the vehicles will be oriented on the requirements of these customers; demand for minibuses and shuttle vehicles may increase as a result. On the other hand the currently most profitable side of the business, sales of cars to private customers, will continue to decline.
Municipalities must already start thinking about autonomous driving now

Road infrastructure should be in the best possible condition. Driverless vehicles will orient themselves to a large extent on the physical infrastructure. Road space will have to be very clearly defined to make autonomous driving safe and trouble-free. We must assume that many roads will need to be redesigned in order to organise how passengers board and alight from self-driving vehicles, while superfluous parking spaces can be used in different ways. This will require high levels of investment in the long term. Additional intelligent infrastructure will not necessarily be required, however.

Autonomous driving will have positive effects on urban traffic. For example, respondents anticipate that there will be much less traffic searching for parking spaces. Given the provision of attractive mobility services and a higher proportion of fleets of collectively used vehicles, capacity utilisation of vehicles will increase. Fewer vehicles will be necessary, reducing the number of parking spaces required. Even people who don’t own a car or don’t have a driving licence will be able to book a car journey on the spur of the moment, giving them a new mobility option. It will be possible to integrate peripheral areas better using autonomous vehicles. Respondents in the municipalities recognise these opportunities while also estimating that the influence of autonomous driving on traffic behaviour will be relatively small. Here they underestimate the attractiveness of new mobility services. So on average, they view the future development of traffic systems cautiously, based on the current status quo.

The municipalities have only a limited perception of the possible risks linked to autonomous driving. Because autonomous driving will be extremely attractive and readily available, demand for individual car transport may increase, leading to additional stress on the road network. In addition, less dense settlement structures may occur due to the better accessibility of peripheral areas. This may promote additional urban sprawl, tending to result in increased road traffic. However, many respondents did not see this as being clearly influenced by autonomous driving.

Overall the municipalities are uncertain in view of the coming developments. Opinions are divided. Current challenges such as electric mobility, bicycle traffic and traffic management are also still seen as core tasks in future. The challenges that will arise due to autonomous driving do not yet play a central role.

Vehicle manufacturers and component suppliers would like more support in developing autonomous driving in Germany. Relevant aspects include above all setting up field testing areas and research projects, as well as structuring the legal framework. Direct financial support is less urgently required.

There are a great many ways to steer the development of autonomous driving. Respondents for the municipalities recognise that they are not helpless in the face of the development of autonomous driving: they can take transport policy decisions and already implement flanking measures that are in common use; they can make guidelines in favour of certain forms of transport, can influence housing developments and the development of road infrastructure, can influence permits and tariffs for car services and restrict or charge for the use of road infrastructure.

Municipalities must ensure that many of the future steering options for autonomous traffic are developed sustainably. Settlement and infrastructure policy are not the only aspects that must be conceived in long-term cycles. The development of new intelligent traffic control systems and toll systems, or the restriction of approaches, also require preparation time that must be taken into consideration. Municipalities should build up substantial IT expertise to enable them to have influence on autonomous driving in the long term.
2 A much anticipated innovation
Autonomous driving – a definition

SAE International, the Society of Automotive Engineers, and the German Federal Highway Research Institute (BASt) have divided the automation level of vehicles clearly into six levels. Levels 0 to 2 supplement human driving with no or slight automatic support. Levels 3 to 5 refer to automated or autonomous driving (Fig. 3).

At level 1 the human driver receives automatic system support either for steering or for acceleration and deceleration. At level 2 the human driver is supported both in steering and in acceleration and deceleration, while independently carrying out all other aspects of active driving. At level 3, the first of the three levels in the ‘autonomous driving’ category, the human driver is given automatic system support in all aspects of active driving, intervening only where necessary. At level 4 the human driver is given automatic system support in all aspects of active driving, not intervening at all. However this does not yet work in all situations. Only at level 5 does the vehicle take over all driving tasks in all types of complex terrain that a human driver can also be expected to cope with.

The questions in our study referred above all to fully autonomous driving at level 5. Many applications only become possible, or can only be easily and widely implemented at this level. This initially results in a long-term development picture. It will be essential to break down this picture into development stages that are possible in the short and medium term in order to derive short-term recommendations.

<table>
<thead>
<tr>
<th>SAE level</th>
<th>SAE name</th>
<th>SAE definition</th>
<th>Execution of steering and acceleration/deceleration</th>
<th>Monitoring of driving environment</th>
<th>Fallback performance of dynamic driving task</th>
<th>Germany, BASt name</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No automation</td>
<td>The full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Driver only</td>
</tr>
<tr>
<td>1</td>
<td>Driver Assistance</td>
<td>The driving mode-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task</td>
<td>System Human driver</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Assisted</td>
</tr>
<tr>
<td>2</td>
<td>Partial Automation</td>
<td>The driving mode-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task</td>
<td>System Human driver</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Partly automated</td>
</tr>
<tr>
<td>3</td>
<td>Conditional Automation</td>
<td>The driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene</td>
<td>System System Human driver</td>
<td>Highly automated</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>High Automation</td>
<td>The driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene</td>
<td>System System System</td>
<td>Fully automated</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Full Automation</td>
<td>The full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver</td>
<td>System System System</td>
<td>/</td>
<td></td>
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Fig. 3: Automation level of vehicles according to SAE und BASt (SAE’s presentation)
All respondents expect driverless vehicles to be introduced – and soon

Most respondents consider it likely that autonomous vehicles will be introduced into mass production in the period between 2017 and 2030 (Fig. 4). It is estimated that the technology will be controllable and available in the medium term. Mobility service providers and public transport companies are optimistic, on average anticipating the presence of driverless vehicles on the roads as early as 2020. Vehicle manufacturers and components suppliers are less sanguine, locating the first introduction in around 2025.

It is unusual that the users are more optimistic than the manufacturers when viewing the development of a new technology. This is certainly also due to the intensive public discussions in the past year and has been promoted by test drives, some of which were remarkable, and highly automated shuttle vehicles that were introduced last year in some cities during pilot projects, in some cases even on public roads.

Fig. 4: When will the first driverless vehicle be available in mass production?
Driverless vehicles have advantages

All respondents have similar expectations of the detailed characteristics of autonomous driving. Autonomous driving has a range of advantages for the user. Driving time can be used for other activities; in this context respondents mention media use, communication, work or reading (Fig. 5). So a significant advantage of public transport is transposed to individual trips with a self-driving car. In addition, even confidential work and business communication will be possible in individually-used driverless vehicles.

Fig. 5: How would you use time in a self-drive vehicle?

Fig. 6: Characteristics of autonomous driving
Most respondents assume that autonomous vehicles will find parking spaces automatically and that in principle, autonomous vehicles will drive passengers up to their front door (Fig. 6). In other words, in addition to the advantage of using the journey time, autonomous driving also has all the features of taking a taxi. This is particularly relevant in cities where the nearest public car park is often an unpredictable distance from the destination.

At the same time, all respondents anticipate that driverless vehicles will be safer than vehicles with a human driver. This is realistic for reasons of acceptability and as the basis for permits. We need hardly assume that unsafe vehicles will be used long-term. However, when asked whether they would sleep in an autonomous vehicle, there were doubtful voices particularly among respondents from the municipalities and public transport companies. So trust in the technology is not yet complete.

Vehicle manufacturers and components suppliers anticipate that initially the vehicles will be more expensive than comparable cars today (Fig. 7). That seems realistic, given that the additional electronics and IT required will be expensive to develop.

The same respondents estimate, however, that running costs for autonomous vehicles could be comparatively low. The assumed improvements in safety will result in lower insurance costs. Lower energy consumption would be the result of autonomous vehicles’ more efficient driving style and less driving round looking for parking spaces. Expensive purchase prices plus lower operating costs favour use by mobility service providers. In the long term we may assume that autonomous vehicles will also be produced more cheaply for the mass market.

*Fig. 7: Anticipated costs of autonomous vehicles in comparison to current vehicles*
Autonomous vehicles will conquer the market very fast

The advantages of autonomous driving will result in a high level of demand for self-driving vehicles. In fact most respondents think that these vehicles will be introduced into all market segments by 2050 (Fig. 8). This applies equally to all respondent groups.

**Fig. 8: Proportion of autonomous vehicles in relation to all newly registered cars (mean values)**

**Fig. 9: Which autonomous vehicles will be first used in large numbers on public roads? (multiple answers possible)**
Most respondents assume that shuttle vehicles and taxis will be the first vehicles used in large numbers on roads (Fig. 9). This applies above all to mobility service providers as well as manufacturers and component suppliers. The municipalities see great potential for buses, while comparatively few respondents see private vehicles as the main driver of the technological developments.

The responses show that the characteristics of autonomous driving are already anticipated in detail and in similar form by all respondents. Fleet operators have a clear idea of the technology’s possible future uses. The market has time to prepare itself for a concrete product which it predicts will soon be introduced. That also means, however, that a high level of demand must be assumed from day one for every autonomous function that is ready for use.
3 The mobility market is changing
Mobility service providers have new opportunities to shape services

**Taxi services will become cheaper and more widely available.** Drivers will not be needed for the normal operation of autonomous driving services. This will greatly reduce operating costs for this personnel-intensive service. There will be no more bottlenecks due to a lack of qualified drivers. It will be possible to scale up taxi services as required using driverless vehicles.

**Current car sharing and car hire provision will also become much more efficient.** The cost-effectiveness of vehicle fleets depends on a great extent on the degree of capacity utilization. The more often a vehicle is in use, the more effectively the purchase and non-driving operating costs are spread. Autonomous vehicles can be intensively scheduled and – like taxis – positioned to cater for anticipated demand (for example at airports, at event locations, in housing areas in the morning, in business centres in the afternoon). In this way capacity utilization can be maximised (Fig. 10).

**Even partly autonomous vehicles that can move independently in the city at very low speeds will result in improved capacity utilization of car sharing fleets.** This kind of fleet scheduling already exists both with car rental companies and providers of flexible car sharing solutions. Due to the relatively high level of personnel required and the costs it entails, this does not yet make sense for all vehicles and locations.

**Mobility service providers anticipate that added value services will become established for journeys with autonomous vehicles.** When the customer is alone in the vehicle and does not have to pay attention to the traffic, a range of additional services or even advertising-funded journeys could be offered. All the mobility service providers we surveyed predict this.

**There is a market for shuttle transport.** Various model calculations show that if there is sufficient demand, several individual journeys could be combined at short notice if that only entails short diversions. Using vehicles collectively reduces the cost for individual passengers well below that of individual taxis. This type of pooling or shuttle transport is already being developed and offered (using drivers). Driverless vehicles would make these services cheaper and more attractive. The mobility service providers we surveyed are aware of the great significance of collective provision of this kind.

**Mobility services will play an important part in future.** The multiple advantages of autonomous vehicles will reduce costs for mobility service providers. That will lead to increased demand, enabling greater vehicle utilization so that the fleets can be expanded. It will be possible to use autonomous vehicles anywhere and they could be available at short notice, making them extremely attractive.

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**Fig. 10: Advantages from the point of view of mobility service providers**

<table>
<thead>
<tr>
<th>Flexible disposition of vehicles will result in high levels of utilization</th>
<th>-100 %</th>
<th>-50 %</th>
<th>0 %</th>
<th>50 %</th>
<th>100 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Even partly autonomous vehicles will improve car sharing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Added-value services will be provided in autonomous vehicles</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>There is a significant market for shuttle transport</td>
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<td></td>
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</table>
Public transport will become autonomous

The use of self-driving buses will make operation much more cost-effective, as with taxi services. As in the case of taxi operation, personnel costs currently account for a large proportion of the overall costs of bus services.

Public transport companies consider that using smaller vehicles would enable them to provide more flexible bus services (Fig. 11). Corresponding to the cost structure, bus services tend to be infrequent. Even in big cities, few bus routes are served more frequently than every ten minutes. The use of driverless buses would make it possible to replace one large bus with several smaller ones while operating costs would remain similar, so frequency could be increased. It would be possible to provide a regular, attractive service even on little-used routes and at less popular times. In this context, road and bus-stop capacity would only become critical in very central locations.

**Autonomous vehicles would improve operating schedules in bus transport.** There is no need for forward-looking personnel planning when using driverless vehicles. Autonomous buses don’t require either breaks or infrastructure for drivers. They can be operated from any bus stop. The vehicles ‘know’ all the routes and schedules so they can be used flexibly, enabling provision to be increased or reduced at short notice in response to actual demand. In the same way, journeys at weekends or at night are just as easy to provide as on working days. In the longer term, it will be possible to dispense with a large part of the driver organisation and scheduling that currently forms such a central, complex task for transport companies.

Public transport companies also realise how attractive shuttle transport can be, i.e. direct carriage of passengers using smaller vehicles. They surmise that services of this type will generate new demand and gain new groups of customers. Because autonomous transport will probably be available flexibly and at short notice, it will be much more attractive than today’s non-scheduled transport.

![Fig. 11: Operational advantages in public transport](image-url)
Most respondents among public transport companies assume, however, that scheduled bus routes with solo buses will continue to play an important part in urban transport. This clearly demonstrates how important buses are as the traditional standard vehicle in urban and regional transport. Buses consume relatively large amounts of energy and are only efficient when capacity utilization is sufficient. However, passenger numbers in today’s buses are low during large parts of the day. Apart from a few exceptions – mainly in large cities – only a few routes serve heavy demand throughout the day.

The operational advantages of autonomous vehicles mean that public transport companies are extremely interested (Fig. 12). Most respondents think that autonomous vehicles should be integrated into the fleet as soon as they are available. They focus primarily on providing shuttle transport as a supplement to regular services. Respondents anticipate that autonomous solo buses will also be used; however, there is less agreement on this point than for shuttle transport.

Public transport companies even think that the operation of their own robo-taxi fleets may be worth considering. Journeys of this kind would enable them to cover customers’ mobility requirements more fully and could supplement the public transport system.

Time will tell how far scheduled, autonomous road transport services will be worthwhile and necessary. We can assume that in future, the scheduling and organisation of public transport will be very different from today. Autonomous driving will impact bus stops, route planning, vehicle size, and vehicle and personnel planning. If shuttle transport makes direct journeys possible and available, changing to a different public transport vehicle will no longer be necessary. It is not possible to generally predict whether and where demand can really be combined in such a way that large buses on scheduled routes will be necessary. If direct transport becomes much more widely available it is also possible that the shuttle buses will ‘cannibalise’ existing rail and road transport. This may be expected particularly for tangential journeys where it would no longer be necessary to change vehicles at central intersection points.

![Fig. 12: Estimates of the suitability of autonomous vehicles for public transport fleets](image)

Development of flexible collective shuttle transport provision
Integration of autonomous solo buses in the operation (when available)
Development of a fleet of cars as (robo) taxis as part of public transport provision

-100 % -50 % 0 % 50 % 100 %
rather unsuitable rather suitable
Private cars will become less important

Autonomous vehicles will make mobility services much more attractive (Fig. 13). Mobility service providers are convinced that 25 per cent of all inner-city car journeys will be performed by autonomous robo-taxis as early as 2030. That would be a considerable increase compared to the current situation, where all taxi and car sharing journeys together comprise a proportion of about 1 per cent of urban traffic.

Robo-taxi provision could also be cost-effective in medium-sized and smaller towns. Unlike car sharing, the vehicles do not have to be picked up where they were left. In other words, attractive mobility solutions can be envisaged even in areas with little traffic, and even if the necessary empty journeys are longer than in cities.

In the same way, autonomous driving provision is also suitable for long distances. If a vehicle can be used from the passenger’s own front door, it becomes much more attractive than current car hire provision, particularly for long journeys with luggage. For spontaneous journeys, it would provide a good alternative to travelling with one’s own car. If several people travel together, the travel cost per person would be reduced and may be competitive with train and long-distance coach journeys. That will apply particularly if the journeys start or end outside large metropolises.

Public transport companies recognise the greatly improved opportunities to provide connections for peripheral urban and rural areas. They also see increasing chances of participation for groups of people who up to now have had no access to their own private cars.

Not everyone will want to give up their own car – but a private vehicle will no longer be necessary. Mobility service providers and public transport companies will introduce new transport forms. The availability of these services in large and small cities, and the use for long-distance journeys between urban centres, will constitute an alternative to private car ownership for most forms of use.
**Competition or collaboration?**

Intense competition already exists in almost all today’s transport markets (including car hire, rail transport, long-distance coach transport and even air transport). For a long time, urban transport has mostly been organised locally. This applies to both public transport and taxi provision as well as the first car sharing providers. Only recently has this started to change as nationwide and international providers of platforms and urban transport fleets have been introduced. Even though there are still only very few providers of station-bound car sharing models, additional companies are constantly entering the market offering mobility services or information.

If autonomous vehicles are introduced as part of existing fleets, the different types of service will come to resemble each other closely (Fig. 14). Car sharing provision will suddenly look very like taxi services, and car hire companies will basically be providing the same service. The characteristics of this kind of robo-taxi service include many aspects that are already established. Technologies for flexible booking of journeys and cashless payment already exist. Picking up passengers at their front door (taxi), recognition of customers, and monitoring and cleaning of driverless cars (car sharing) and leaving cars in a different city (car hire) are already available. The same applies to satellite navigation systems and routing.

If new providers enter the market in addition to those already represented, a significant number of competitors may be anticipated. As a result, companies will be forced to differentiate their provision. Urban passenger transport offers many opportunities for this: providers could identify themselves for example by vehicle quality, individual or collective use, availability and waiting times, or a range of pricing models. In the end, attractive offers will emerge. Public transport companies fear that they could lose customers to this kind of individual door-to-door journey provision (Fig. 14).

In the long term, the future of classical public transport will be called into question. More competition must be anticipated, particularly in the field of shuttle transport. If collective services can be provided that are comprehensive, cost-effective and cheap, private companies will enter the market. Public transport companies will become just one competitor among many others.

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**Fig. 14: Competition among mobility service providers**

MOBSP: increasing similarity of car hire, car sharing and taxi is very likely

PTC: robo-taxis could result in PTCs losing customers
The initial response of most respondents is that collaboration is a suitable measure to drive forward the introduction of autonomous driving (Fig. 15). Public transport companies view networking with other transport companies as a suitable means of preparing themselves for autonomous driving. Many respondents also consider that new forms of collaboration with mobility service providers may become important. Respondents among mobility service providers almost all share the same view: the entire future market for autonomous mobility services will be huge. It will probably be difficult for any single provider with their own vehicles to implement comprehensive coverage of every city and region plus long-distance routes that would permit their customers to book a spur-of-the-moment journey anywhere and at any time. Collaborative arrangements will certainly be necessary, particularly in order to establish autonomous driving services.

Most respondents among mobility service providers consider the development of digital user interfaces to be very important (Fig. 16). To succeed in the market, providing customers with easy access to services is just as important as providing reliable travel information. Customers’ journey requirements must be recognised at an early stage, particularly in relation to journey bookings at short notice and in order to provide services that adapt dynamically to the market. Data analysis can enable providers to anticipate types of use and to optimize their operation. The customer interface and dealing with available demand data can only be realised using a digital interface and intensive data management. The public transport experts surveyed attach less importance to this type of customer access.

In the long term, providers will develop specialisations and a range of value chains. Many urban factors will influence the differentiation of provision and the demarcation between public transport and private services. Some influencing factors include settlement structure, public transport provision (particularly rail transport), and the socio-demographic distribution of the population.

![Fig. 15: Collaboration in the development of autonomous services](image)

![Fig. 16: Development of customer interface when organising autonomous services](image)
4 Rethinking cars
 Autonomous vehicles go digital

Vehicle manufacturers and component suppliers anticipate that in future, IT components will comprise over 50 per cent of autonomous vehicles’ added value (Fig. 17). That is a considerable increase of about 70 per cent compared to traditional cars. Only those companies that have the necessary IT competence in the production and integration of hardware and software will really benefit from autonomous vehicles.

There was no clear answer to the question put to all participants about who will be first to develop a driverless vehicle – IT company or vehicle manufacturer. The manufacturers themselves are optimistic and tend to be more confident that they will develop a driverless vehicle (Fig. 18). About 60 per cent of the OEMs view themselves as being in the better position, although about 25 per cent of OEM respondents are of the opposite opinion. Respondents from municipalities and public transport companies also see advantages for vehicle manufacturers. Mobility service providers, on the other hand, tend to expect IT companies to be successful. Currently, all kinds of collaborations are involved in the development of autonomous vehicles. In the end, however, it does not matter to users and municipalities who actually develops and produces the vehicles.
Safe, certified, fully-autonomous vehicles will not be available any time soon. IT systems development must make significant advances before it can develop systems that cover all possible application fields. Manufacturers and component suppliers agree that current concepts from the Connected Car and Driver Assistance fields are not sufficient. Considerable advances in IT development and self-learning systems are essential (Fig. 19). Other points mentioned by respondents include new simulation environments and secured, certified software development.

Respondents also assume that great improvements must be made in the area of IT security (Fig. 20).
The legal framework is a core topic

Permits for autonomous vehicles will not granted automatically. Manufacturers and component suppliers assume that the first permits will not be granted in Germany or Europe, but in North America and China where the legal and political framework is considered more favourable. None of the respondents expect that EU-wide permits for autonomous vehicles will be granted first (Fig. 21). That means that the permitted vehicles will initially have to operate within the US or Chinese frameworks and conditions.

The legal framework, user acceptance and infrastructure requirements are viewed by all participants as the biggest obstacles to the introduction of autonomous vehicles. In this context, the views of manufacturers and suppliers are relatively similar to those of all other respondents (Fig. 22). Over 90 per cent of manufacturers and suppliers consider the shaping of the legal framework to be of key importance.

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**Fig. 21:** Where will fully autonomous vehicles first be granted operating permits?

**Fig. 22:** Biggest obstacles to autonomous driving
Vehicle manufacturers and suppliers also anticipate great demands on infrastructure. Other respondents, on the other hand, tend to see user acceptance and technical reliability as obstacles. Purchase costs of the vehicles and data protection were generally estimated to be less relevant; nor is possible political resistance seen as a great problem. In this context however the respondents’ opinions differ widely: manufacturers and municipalities anticipate no obstacles at all here, while public transport companies and mobility service providers as possible providers of journeys in autonomous vehicles predict a certain level of risk.

Support is necessary

Vehicle manufacturers expect first and foremost political and practical, rather than financial, support. The essential importance of the legal framework is also reflected in the manufacturer’s assessment of how public authorities could promote autonomous driving (Fig. 23). All respondents among the manufacturers consider the clarification of permit issues to be important, followed by provision of field testing areas, investment in relevant road infrastructure and research funding. In other words, they only expect things that public authorities are already responsible for. Manufacturers are obviously confident that they themselves can push ahead with and organise the actual development of autonomous vehicles.

![Fig. 23: Manufacturers’ expectations – how should public authorities promote the development of autonomous driving?](image-url)
Driving will become less important

Vehicle manufacturers and component suppliers assume that driver-specific features will become comparatively irrelevant in autonomous vehicles. Only a few respondents estimate that attractive operation in non-autonomous mode (if such a thing is even available) will be important (Fig. 24). Good visibility for the driver will not be particularly important when the vehicle sensor system takes over the driving task. They also assume that the type of drive will not be particularly important to the user. Alternative drive forms are not seen as particularly relevant.

Manufacturers and suppliers assume that typical features and fittings will continue to be important (Fig. 25). These include seats, air-conditioning and space provision among other things, as well as the flexible organisation of the interior and the seat arrangement. This becomes relevant as soon as the ‘driver’ can do other things during the journey. The boot is seen as unimportant, suggesting that it could be omitted for the majority of standard vehicles. The classical travelling limousine that covers all possible types of use will no longer be needed if a specific type of vehicle is available for journeys where more space is required for passengers or load.

Fig. 24: Important features and fittings for autonomous vehicles (drive/driving)

Fig. 25: Important features and fittings for autonomous vehicles (space /comfort)
Vehicle manufacturers and component suppliers predict that passive safety – an important element of today’s vehicles – will become less significant (Fig. 26). That seems likely if one assumes that the autonomous driving operation will include (pro)active safety. If it is no longer necessary to protect the driver physically to the same extent, it may be possible to produce smaller, lighter vehicles. Dedicated driver assistance systems will be less important than in today’s cars, because this will be part of the autonomous driving function.

Manufacturers and suppliers anticipate that sensor systems will be extremely important. In order to drive safely, the vehicle must be able to apprehend its external surroundings accurately. Remote diagnostics and remote maintenance are estimated to be almost equally important. Autonomous vehicles will be complex products with many electronic and IT components. Users of autonomous vehicles will neither be willing nor able to perform status monitoring and checking. That makes it all the more important that the critical safety technologies and operational capability are continually and automatically monitored. Many upgrades and repairs could be carried out remotely. In the end, the user will have far fewer opportunities to monitor and intervene than with traditional vehicles.

According to car manufacturers and suppliers, digital demands on the vehicles will be extremely high (Fig. 27). The vehicle will have to be integrated into a network and the passengers will want to use their own digital environment at the same time, whether for work or leisure. This environment must be easily adaptable to changing passengers if the vehicles are primarily subject to temporary usage. Entertainment is also predicted to be very important.

![Fig. 26: Important features of autonomous vehicles (safety)](image)

![Fig. 27: Important features of autonomous vehicles (digital systems)](image)
Autonomous vehicles must comply with the requirements of fleet operators

Vehicle manufacturers and component suppliers anticipate that the proportion of private buyers will decline markedly (Fig. 28). Instead, demand from car hire companies, mobility service providers and other commercial customers will increase. It remains to be seen to what extent company cars will also be provided or managed by fleet operators. It will not be necessary for many commercial customers to have their own fleet if individual journeys can be booked at any time for most requirements. In any case the demand side will become increasingly professionalised. The fact that manufacturers will lose contact with the actual users of their vehicles has already been often described.

Mobility service providers assume that the proportion of autonomous vehicles in fleets will reach 49 per cent on average once they have been successfully introduced into the market (Fig. 29). Taking into account that vehicles in car hire fleets are regularly replaced, providers could quickly replace their fleets with new autonomous vehicles.

Vehicle manufacturers and component suppliers predict that mobility service providers will require a range of different vehicles. When a car journey is booked as a service, a specific vehicle can be used for each individual journey according to the journey’s purpose. We can assume that different vehicle designs will be used for inner-city and long distance journeys, journeys with collectively-used vehicles or with more load space. Respondents among the manufacturers and suppliers expect that above all, demand for minibuses will increase (Fig. 31). Demand for top class vehicles is predicted to remain unchanged. In all other classes, changes are expected but the varied opinions do not give a clear picture overall.
Autonomous driving will promote electric mobility

Most respondents are optimistic that autonomous driving will reduce the obstacles for electric-powered vehicles entering the market. Mobility service providers and public transport companies in particular recognise the added value of autonomous driving for electric vehicle fleets (Fig. 30). The availability of car charging infrastructure is a significant bottleneck for the establishment of electric vehicles, particularly in cities. Charging points are not always near the desired destination or are already occupied. An autonomous car could network independently and drive itself to the nearest charging point. Charging infrastructure could also be concentrated as petrol stations are today, or be mainly installed in multi-storey car parks. This would both improve the appearance of roads and considerably reduce the construction and maintenance costs of charging points. Once vehicles are autonomous, the operating range of electric vehicles in cities is no longer an important issue.

Urban car sharing and car hire fleets will become electric. Above all in vehicle fleets, vehicles can be taken out of operation and charged at short notice according to demand, without reducing service provision. Today, electric cars in car-sharing fleets are often not parked on charging stations and must be time-consumingly relocated by company personnel.

![Fig. 30: Reduction of obstacles to market entry for electric drive cars](image)

![Fig. 31: Influence of autonomous driving on vehicle types](image)
5 Municipalities must get prepared
**Autonomous driving will influence how different means of transport are used**

In a world where car driving is very appealing and where it becomes cheaper due to shared car use, demand for individual motorised transport may increase at the expense of other transport providers. This would increase the strain on available infrastructure that is already under stress. Even if driverless cars use road space more efficiently, traffic congestion and energy consumption would increase. New, less dense settlement structures could arise since it would be easy to connect them to the city: these new structures would depend on cars as a means of transport, which would reinforce the effect. Users would accept the longer journey times if they could use the journey time for work.

**On the other hand, driverless vehicles could also be a welcome alternative for urban transport systems.** They would enable improved transport links to areas that are currently not well connected. It would be possible to reorganise public transport by using shuttle vehicles and autonomous buses, so it might break even financially. Private vehicles would no longer be needed and most car journeys could be provided by mobility services. This would free up most public car parks and limited road space could be used differently. Individually booking and paying for each journey would make users aware of the costs of each journey; this would mean that they would use collective provision more often. The fleets would be electrically powered, resulting in considerable long-term reductions in traffic emissions.

**In the end, the development will be somewhere between these two positions.** Autonomous driving will impact urban transport in different ways. The effects will depend to a large extent on local conditions. This is where municipalities can exert an influence and play a decisive role in shaping how things develop.

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![Fig. 32: Impact of autonomous driving on how means of transport are used](image)
The municipalities’ assumptions about the development of transport use shows great uncertainty and an unclear image of the future (Fig. 32). First of all, most respondents clearly envisage increasing numbers of robo-taxis at the expense of today’s taxis. The influence of autonomous driving on public transport or on new innovative forms of provision are mostly assessed as natural or positive. Some respondents view this more critically, however. The assessments relating to other vehicle types are less clear. That can be seen most clearly in relation to private car transport. Almost 50 per cent of respondents think that this will tend to benefit from autonomous driving while many expect the exact opposite. In other words, an influence is clearly perceived, but its direction cannot be predicted.

The effect on pedestrian and bicycle transport is somewhat clearer. At any rate, 30 per cent anticipate rather negative effects. Only a few experts anticipate a positive influence on pedestrian and bicycle transport. This possibility cannot be entirely dismissed in cities, for in this way routes to shops can be made easier or be directed to new destinations.

**Autonomous driving could improve the urban transport system**

Respondents among the municipalities anticipate that self-driving vehicles will reduce the amount of cars hunting for parking spaces, something that currently comprises a significant proportion of urban car traffic (Fig. 33). Driverless vehicles will ‘know’ parking spaces and can independently drive directly to them.

Municipalities expect the level of car ownership to decrease. Fewer private vehicles will be required in urban areas and those that remain will tend to be jointly used by several people. Respondents among the municipalities anticipate a rather moderate decrease rather than a dramatic reduction in the number of vehicles.

Municipalities consider it likely that car parking space will be reduced in urban areas when autonomous vehicles are introduced. However the number of optimists is limited. Over 30 per cent of respondents assume that autonomous driving will have no influence on urban parking space requirements.

![Fig. 33: Opportunities autonomous driving may bring to urban areas](image)
Municipalities see great potential for public transport in the urban periphery. Where bus transport in its current form is neither efficient nor attractive, autonomous vehicle provision will provide improved connections.

However, only 40 per cent of respondents among the municipalities believe that mobility services will be attractive and available at low cost. An almost equally large proportion is not convinced of this. If using a private car is still expensive, or if owning your own car is actually more appealing than the mobility services, then autonomous vehicles will have little influence on current urban transport systems. That is also shown by the ambivalent estimates as to whether autonomous driving could improve participation for those population groups who are less mobile at present (such as older people, schoolchildren, people with limited mobility).

Not all respondents among the municipalities expect autonomous driving to have a significant impact. This is reflected in the municipalities’ rather indifferent estimates of risks for urban areas (Fig. 34). They tend not to envisage increased demand for individual motorised transport, therefore they expect no increase in stress on the road network. The danger of urban sprawl is seen as more of a problem, but again, not by all. The mood among respondents is very varied.

In view of the advantages for customers as described above, the interest of potential providers and the probable competition, the potential for new types of mobility provision is very high. Urban transport systems will be characterised in the autonomous driving future by varied robo-taxi and shuttle services. We may assume that – at least in big cities – several services will become established in competition with each other. This kind of provision will add a new component to the transport system and will initially offer the population additional, flexible alternative ways of carrying out their journeys. The range of new mobility options will produce a complex selection of transport means that differs widely from today’s situation.

The impact on urban traffic is therefore likely to be on a larger scale than municipalities so far assume. Will autonomous mobility services become so attractive that demand for car transport increases markedly? There is no simple answer to this question. The form of the services will also depend on settlement structures, socio-economic conditions and existing transport networks. These differ from city to city, so the impacts of autonomous driving on cities need to be examined locally and in detail.

![Fig. 34: Risks for cities](image-url)
Municipalities can shape developments

The impacts of autonomous driving on urban areas depend on how future transport systems with their diverse options are used. In view of the shortage of inner-city space, energy consumption and mobility emissions, the aim should be to design the future of motorised transport to be as efficient as possible.

Municipalities have a range of possible ways to exert influence on autonomous driving. We will describe these in the following pages. Current approaches such as developing road infrastructure, expanding and funding public transport, parking space management, and road traffic management and information cannot be transferred unchanged to the autonomous driving future.

Municipalities view the promotion of public transport and car sharing concepts as a relevant measure to influence the development of autonomous driving (Fig. 35). Municipalities recognise that the topics of public transport and car sharing could have positive effects on the development of autonomous vehicle use. These transport providers can already be supported and expanded today. In this way the use of driverless vehicles can be tested and the transport system be adapted to some extent to the expected future options.

Awarding concessions and the municipalities’ influence on tariff structures of services offering autonomous vehicles are less suitable instruments to steer the use of autonomous vehicles (Fig. 36). Interventions of this kind in the anticipated competition may restrict new, creative solutions. The wide range of potential mobility services and tariff systems would make it difficult to implement a unified tariff.

Fig. 35: Possible ways in which municipalities could steer the use of autonomous vehicles (car sharing and public transport)

Fig. 36: Possible ways in which municipalities could steer the use of autonomous vehicles (concessions and tariffs)
Traffic management is essential in order to manage autonomous transport

Intelligent road traffic control is viewed by the municipalities as an important approach to organising autonomous driving (Fig. 37). From what we know today, traffic flow can be optimised by improved dynamic traffic information, controlling traffic signals, harmonising speed and influencing routing decisions. The actual intervention in traffic participants’ decision-making is usually relatively small; this kind of traffic management does not initially put anyone under pressure. So it is easy to understand the high level of agreement among respondents to intelligent traffic control. However it is not yet really clear to what extent the use of autonomous vehicles will affect traffic flow and how exactly the latter can be improved.

The municipalities also assess parking space management as very positive. At first sight, that is surprising. Considering that autonomous vehicles do not really need their own parking space, the lack of parking spaces or charging for them should not really directly influence use of transport means. On the other hand, of course it is not efficient even for autonomous vehicles to drive around the city non-stop, so parking space management could also be helpful in controlling access to certain areas and minimising the amount of traffic hunting for parking spaces. However this will tend to affect individually occupied vehicles rather than mobility providers who are relatively frequently on the road.

Municipalities also see interventions in autonomous vehicles’ routing decisions as a useful measure to control the use of autonomous vehicles. That applies to access restrictions for individually-used vehicles and prioritising collective vehicles. Closing certain routes can definitely be a sensible measure to prevent through traffic from using roads in residential areas.

Fig. 37: Suitable options for municipalities to control the use of autonomous vehicles (traffic management)
Exerting control in this way constitutes an intervention in the free use of road infrastructure, however. The political discussions and the precise definition of the vehicles affected will not be easy. If we assume that autonomous vehicles will mostly use main roads, like current satnav systems, it will be relatively simple to exert this influence from the technological point of view. Restricting access to roads with particularly high levels of traffic in the inner city would not be a problem and could easily be monitored.

Respondents among the municipalities view the restriction of empty journeys by autonomous vehicles as rather less effective. It would probably be comparatively difficult in technological terms to implement and monitor such restrictions. Empty journeys are necessary in order to use autonomous fleets efficiently. The destinations and reasons for empty journeys need to be observed in detail. This will only be possible through access to the vehicles’ IT systems.

Dynamic road use fees or city tolls are additional possible measures to control the use of autonomous vehicles, but are assessed as rather unsuitable by many respondents. Yet charging for the limited commodity ‘road infrastructure’ can in principle have a positive effect on distribution of demand. A road use fee is neutral and does not discriminate against any of the different mobility providers. The charge for the use of collective vehicles would be cheaper than for individual services. The technological equipment for a sufficiently simple and fair toll would be expensive, however. It would also probably include accessing vehicle data.

The technologies required for comprehensive, effective traffic management demand that municipalities have a high level of technological understanding for digital systems, vehicle interfaces and for mobility providers’ business models and interests. Many of these intelligent technologies have been under development for a long time and could already be implemented today. However, really intelligent traffic control would probably require communication and data exchange with the vehicles. In this context, in the long term it should be considered whether specific infrastructure will be required to realise these traffic control measures, or whether digital and virtual solutions will suffice.
The physical infrastructure must be upgraded

The majority of respondents among the municipalities anticipate that the existing infrastructure will need to be upgraded to make it suitable for autonomous driving (Fig. 38). Vehicle manufacturers and component suppliers agree. Demands will be made on the quality and maintenance of the existing physical road infrastructure. Road conditions, clarity of traffic situations and right-of-way situations, and good road markings and signs will all contribute to safe automated traffic operation. The technological advantages will not be fully utilised in cities where the road infrastructure restricts the use of autonomous vehicles. If a driver must repeatedly take over operation of the vehicle, this will limit the full professional use of autonomous vehicle fleets.

Municipalities assume that intelligent infrastructure will be required to operate autonomous vehicles. Manufacturers and component suppliers, however, do not share this concern. Autonomous vehicles that depend on a specific infrastructure could only be used in a limited way. The technology would have to be standardised and it would also need to be installed everywhere and continuously available. The expense of constructing and maintaining this kind of unified infrastructure would be prohibitive, making it almost impossible to realise in Germany. Manufacturers are therefore unlikely to pursue this direction of development.

Neither municipalities nor manufacturers and suppliers see a need for autonomous vehicles to have their own lanes or routes. They will probably run on normal roads.
Municipalities view the upgrading of infrastructure for autonomous vehicles without enthusiasm (Fig. 39). Autonomous vehicles will only be an attractive option if they can really operate. For this to happen, the road network must have sufficient capacity. In view of today’s infrastructure policy and the limited space available in urban areas we cannot assume that large numbers of new roads will be built. In addition, upgrading roads for autonomous vehicles is likely to lead to an increase in traffic.

Nor do municipalities view upgrading pavements and cycle lanes as a suitable method of controlling autonomous vehicle use. Good cycling and pedestrian infrastructure offers alternatives to the use of autonomous vehicles. However, the limited road space has to satisfy all transport providers and forms of use. Discussions about road use will become much more complex when autonomous vehicles and a wide range of mobility services (robo-taxis and shuttle transport) are introduced.

Municipalities consider that in any case, small-scale adjustments to infrastructure will be required, for example so that vehicles can take on passengers. If autonomous vehicles take on passengers at the roadside like taxis, this could quickly cause confusing situations. Autonomous transport could be organised by zones where passengers can enter and leave vehicles, combined with reorganisation of parking spaces. It therefore seems both necessary and sensible in the long term to redesign roadsides. Interaction between autonomous vehicles and other road users, particularly cyclists and pedestrians, must also be clarified. Clear traffic guidance and regulations could help avoid uncertainty in this context.

Some municipalities have also mentioned settlement policy as an additional important means of influencing autonomous driving. With the availability of easy, cheap autonomous journeys, less dense settlement patterns would promote or even require individual car journeys. That would result in increased stress on the road network. Denser settlement patterns and good provision of collective transport could restrict this development.

Fig. 39: Ways of controlling the use of autonomous driving (transport infrastructure)
Communication, maps and traffic data are important

Both municipalities and vehicle manufacturers and suppliers consider that fast, available mobile communication is an essential basis for autonomous driving (Fig. 40). Completing a secure mobile wireless network across whole areas should be a matter of high priority.

Precise maps are equally important for vehicles’ autonomous navigation. To respond to driving commands, the car must recognise its position on the road. As well as sensors that scan the environment, map data provide important information for autonomous driving. Current approaches link these two technologies. We may assume that vehicle manufacturers will develop their own maps and adapt them continually so that they are sufficiently precise and up-to-date. Autonomous vehicles will record current route information and pass it on so that the maps can be dynamically developed. The municipalities’ role here is not yet clear.

Traffic data and traffic congestion information are important for autonomous vehicles’ routing decisions. Municipalities attach more importance to this information than manufacturers do. Route selection is up to the vehicle, whereby routing decisions are made according to clear patterns or user preferences. Generally vehicles will attempt to find out the fastest route at any given time. A range of traffic congestion information for satnavs already exists today. However, very few people use their satnav in the cities. Research is needed into the degree to which the strict application of fixed routing algorithms actually results in optimisation of road use.

Information about roadworks is also important for availability of autonomous vehicles, according to municipalities and manufacturers. Roadworks influence the road network capacity; information about current obstacles supports vehicles’ navigation. Roadworks are also important in relation to safety. If vehicles recognise them too late or incorrectly, this could lead to accidents or unsafe manoeuvres. Precise roadworks information, allied with the vehicles’ sensor systems, could help vehicles to make the correct driving decisions. The quality of temporary roadworks installations will also become very important. Considering the roadworks data currently available and how varied roadworks installations are, it is clear that there is plenty of room for essential improvements in this field.

![Fig. 40: What communication forms/data must be available for fully autonomous driving?](image-url)
6 Our recommendations to market participants
Preparations for autonomous driving start now

We asked mobility service providers, public transport companies and municipalities how far they currently take autonomous driving into account. The responses reveal considerable differences: while over 50 per cent of the mobility service providers we surveyed have already appointed a member of staff for this field or are planning pilot projects, this applies to only 25 per cent of the municipalities and public transport companies (Fig. 41). Vehicle manufacturers and large components suppliers have already been intensively working on this topic for a long time.

We have derived recommendations for the different market participants from the survey findings and the projected future developments. These recommendations, presented below, include the essential strategic and practical tasks that should be taken into account in view of the anticipated introduction of autonomous vehicles.

Essential for the implementation of autonomous driving will be a wide range of pilot projects, obviously pursued by vehicle manufacturers and component suppliers and for which municipalities and federal states will provide dedicated field testing areas. It is important to concentrate not only on vehicle development as such, but also to consider future uses, in order to develop the components to suit the actual demands of a future autonomous transport system. Public transport companies and mobility service providers also support projects of this kind (Fig. 42). The projects should be implemented in a structured, comprehensive and coordinated way to enable all participants to gain the maximum information in their joint interests.

![Fig. 41: How far do you already address the topic 'autonomous driving'?](image)

![Fig. 42: Are pilot projects a suitable method of approaching autonomous driving?](image)
Vehicle manufacturers and component suppliers

1. **It is essential for manufacturers to develop and market autonomous vehicles as quickly as possible.** Autonomous vehicles will be in great demand as soon as they are available. They have such a range of advantages for users, above all for mobility service providers, that they will penetrate the market very fast. In the long term, self-driving vehicles will become standard and will largely replace traditional vehicles.

2. **Manufacturers must prepare for new customers.** Mobility service providers, public transport companies and fleet operators will play an important part in the future mobility market. They could cover a large proportion of all car journeys through a range of new business models.

3. **In the medium term, the development of new driverless vehicle models should be oriented on new vehicle concepts.** The types of vehicles demanded will be dictated by the requirements of mobility service providers and new ways in which passengers will use vehicles. In particular, adjustable customer-specific configurations such as individual settings for seats, air-conditioning, mood and entertainment electronics must be provided for. On the other hand, the classic limousine model that caters for a range of purposes will no longer be needed. Vehicle designs can be optimised for specific journey purposes. There will certainly be a significant market for shuttle vehicles and minibuses. It is not clear whether there will be long-term demand for the classic large solo buses for urban public transport.

4. **Vehicle manufacturers and component suppliers must go for the right drive technology.** Autonomous fleet vehicles will probably be electrically powered. Driver experience will play a minor role and motor power will no longer be an important characteristic. For driverless vehicles in professionally-operated fleets, range will only be important for long-distance journeys. That is why the technology with the lowest overall costs will carry the day.

5. **Vehicle manufacturers should develop their own autonomous driving functions and specific sensor systems, or at least ensure the best possible access to these features.** The autonomous driving function will be the core competence in a market oriented on autonomous vehicles. IT components will comprise a large proportion of the total added value and will be an essential factor in differentiating between competing products. Comprehensive IT know-how is required in order to develop autonomous vehicles. The demands placed on sensor systems, software and tests go way beyond any currently existing concepts of vehicle development, so extensive further development is required. The issue therefore arises of how far the expense of development can be shared through collaboration, without losing know-how that is important to each company’s own brand.

6. **Component suppliers must redefine their share of the value chain.** To do this, they must analyse the significance of vehicle components in view of the projected applications and vehicle designs. They must also evaluate what shares of value creation and development they can take on in order to adapt their product range appropriately. New vehicle integration companies may emerge in addition to the classical manufacturers and suppliers; these would then also become customers of the suppliers.

7. **The development of technologies and applications in the fields Connected Car and automated driving should be aimed at fully autonomous vehicles.** As soon as vehicles are fully autonomous, many driver assistance systems will be absorbed into the autonomous driving function. Due to the high infrastructure costs and organisational effort involved, partial autonomy will not make economic sense in many cases, since it will predictably be replaced by fully automated concepts. Interim technologies should only be developed if they are part of the development path to fully autonomous vehicles or if they serve a particular business case. Possible applications, specific usefulness for the user and the relevant market are all factors to be considered in the development of autonomous systems. For example, the advantages of autonomous driving on motorways for logis-
tics and long-distance coach companies are obvious. In cities, vehicles that drive autonomously at low speeds will be useful for mobility service providers, but only if they can really move around independently.

8. **Intense efforts should be put into developing remote diagnostics and remote maintenance.** For safety reasons in particular, these aspects will be essential for vehicles with increasing amounts of sensors, electronics and software components. Secure data acquisition, configuration changes and updates will be of decisive importance in this context. In fleet operation, anticipatory maintenance will increase vehicle availability and result in reduced costs and improved service.

9. **The demands placed by autonomous vehicles on infrastructure should be specified and agreed on at an early stage.** A vehicle that cannot use all roads or operate in all cities due to infrastructure conditions will not be attractive. Existing conditions vary widely between countries, but also between individual cities. This applies both to infrastructure guidelines such as road width, road markings, signs, and design of junctions and cycle lanes as well as to traffic and priority rules or the way in which means of transport are used in the city (e.g. a large proportion of cyclists). When developing autonomous vehicles, therefore, manufacturers should collaborate closely with different cities to enable them to estimate what physical infrastructure must be reliably available and what standards most cities can guarantee.

10. **Autonomous vehicles must be developed and tested in a range of environments.** It is anticipated that the first permits for fully autonomous vehicles will be granted in the USA and China and that they will therefore penetrate those markets first. This makes it essential to develop vehicles in these areas, but that cannot replace tests in other areas and markets. Experience with specifically European conditions can only be gained through field tests in Europe – simply transferring technical experience and applications from the USA and China to countries in the European Union will probably be impossible.

11. **Vehicle manufacturers must consider whether they intend to provide their own driving and mobility services, thus becoming mobility service providers in their own right.** This would enable them to provide a larger share of the new value chain. Manufacturers could distinguish themselves from competitors not only through vehicle characteristics but also by the quality of service they provide. In addition, this would enable them to maintain direct contact to users and passengers. This approach might also result in these manufacturers losing other mobility service providers as customers, however.

**Municipalities**

1. **Municipalities must examine the potential influences of autonomous driving on transport systems.** These will vary from city to city. The focus should be on the development of a range of new mobility services from robo-taxis and shuttle transport to interconnected mobility services in public transport. Traffic models are a suitable way of testing medium to long-term developments, taking into account a range of scenarios in terms of choice of transport means. Various possible interim stages of development should be modelled. This will provide an indispensable basis for understanding possible developments and make it easier to set the course and take long-term decisions about settlement patterns and infrastructure.
2. When planning new, expensive infrastructure, possible effects of autonomous driving on user evaluation should also be considered. Particularly in view of protracted planning and implementation processes, it is possible that the planned transport system will not satisfy later demand. This applies to both road and rail transport. Although future choices of transport means are not clearly predictable, so that they can only be taken into account using development scenarios, it should not be assumed that things will not change.

3. Investments in applications and infrastructure on the basis of automated interim technologies should be carefully examined with an eye to long-term usage. These deliberations should always keep long-term technology scenarios in focus.

4. Thorough investigations are required to estimate the influence of driverless vehicles on road performance. Self-driving vehicles will share the road network with other motorised and non-motorised means of transport. At present it is impossible to foresee whether dedicated lanes or routes will be available in cities. The capacity of the road network therefore depends to a great extent on how autonomous vehicles interact with other road users. The relations are still not at all clear – above all for possible interim development stages when autonomous and traditional vehicles are operating alongside each other.

5. It is imperative that municipalities hold discussions with vehicle manufacturers about necessary physical infrastructure. The important thing is to clarify what infrastructure will really be essential for the safe, continuous operation of autonomous vehicles. The interaction of driverless vehicles, cyclists and pedestrians is a very important topic in this context. The urban infrastructure will determine to a great extent what services are provided using autonomous vehicles and what advantages are gained from the technology. It is certainly possible that provision will vary from one city to another, or that initially, only limited use will be possible. In the long term, regulations for designing roads must take account of the possible requirements of autonomous driving. This will require close coordination between cities.

6. Municipalities should support and promote the development of fast mobile communications networks. This is an essential foundation for autonomous driving.

7. Municipalities and vehicle manufacturers must jointly agree on the degree of data exchange with autonomous vehicles that they aim for and what data must be publicly available. Among other things, data may be required to guarantee the safe operation of driverless vehicles, to enable the vehicles to be influenced or to clarify liability issues. That applies both to the vehicle data as well as that of mobility service providers and fleet operators. Above all, municipalities should define what role they wish to and must play in the long term in terms of preparing map material, traffic information and roadworks data.

8. Long-term prospects and concepts must be developed for adapting existing infrastructure to autonomous driving. Autonomous driving will alter the way road infrastructure is used. Topics include for example picking up passengers at the roadside, access to the inner city, approaches to shopping centres or changing vehicles at stations or bus stations. Fewer parking spaces will be required in cities, opening the way for alternative uses. Municipalities should ensure the early development of ideas relating to which road spaces can be made available to which road users and how new means of transport can also be integrated in this process.
9. **Municipalities must define conditions for granting permits for new mobility services.** A large proportion of inner-city journeys using driverless vehicles will probably be carried out by mobility service providers and/or public transport. In view of the likelihood that shuttle services will be offered as part of their service provision, the new services will not fit the current definitions of public transport, taxi and car hire industries. These types of service must be reorganised, for example in relation to safety, quality, conveyance obligation and data exchange with the operator. These considerations are particularly important when long-term concessions for public transport are granted in the coming years.

10. **Municipalities must consistently develop IT competence at an early stage.** Intelligent traffic systems are one central starting point in order to control future traffic using autonomous vehicles. A wide range of different technologies could be important in this context: from interventions in free routing decisions and intelligent traffic technology to toll systems. It usually takes a long time to develop and implement concepts of this kind, so it is important to discuss concepts and where influence is desired at an early stage, to ensure that the technologies are available at the same time as the vehicles. This also applies to possible interim stages of automated driving at levels 3 and 4. It is likely that public authorities will also require comprehensive knowledge of IT in order to facilitate and steer the necessary development processes.

11. **Municipalities should support and initiate pilot projects at an early stage.** This will help in understanding technologies and future business models. The expansion of car sharing, automatic parking functions, new shuttle services (with drivers) or the use of the first autonomous vehicles in the city are relevant initial steps that reflect the various components in the future means of transport. Vehicle manufacturers, mobility service providers and public transport companies are all extremely interested in pilot projects and field testing areas. Support for projects like this would meet with general approval. In this way, municipalities could bring their requirements into the discussion and exert influence on the organisation of autonomous driving from an early stage.

### Public transport companies

1. **Public transport companies should analyse how far autonomous vehicles could improve their own provision and operation.** This will entail fundamental questions about current forms of service and vehicle sizes. Autonomous vehicles could enable a complete reorganisation of existing bus transport. Small driverless vehicles scheduled frequently would enable both more efficient operation and increased usefulness to customers. Flexible, direct bus transport resulting in better connections could make public transport more attractive and gain new customer groups. In peripheral regions, autonomous mobility connecting with rail transport could increase demand for public transport. For public transport to remain viable it must offer a level of service that is currently only available along very busy routes in large cities. Bus routes with long waiting times and awkward changes will not survive as soon as autonomous shuttle vehicles are available.

2. **Strategic preparation is necessary in order to provide competitive services.** Coordination of individual journeys will lead to the emergence of a new type of transport, something between public transport and individual transport; thanks to autonomous vehicles, this type of service may even be able to operate cost-effectively. It is also likely that private providers will offer attractive new mobility services that provide advantages similar to those of public transport. To estimate the possible impacts of such comprehensive changes, operational concepts with driverless vehicles could be anticipated. Public transport companies should establish whether and where they wish to bring their experience to the table and take part in competing for this kind of provision or whether they prefer to restrict themselves to their core competence: coping with mass transport. This decision may look very different in different areas, depending on local conditions.
3. **If public transport companies do decide to provide autonomous shuttle services or robo-taxi journeys, the budget for new vehicles will need to be flexible.** This would enable autonomous vehicles to be integrated in the fleets as soon as they are available. Possible competitors will probably adapt their fleets in a dynamic way and implement new offers quickly and comprehensively.

4. **Autonomous mobility scenarios should be taken into account before making new investments in complex transport infrastructure.** Autonomous driving may have a large impact on transport demand. It is not yet clear how this will impact underground, suburban rail and tram services. Even rail transport could lose passengers if new, tangential shuttle services come into operation. The question arises of whether new decentralised shuttle services could also satisfy demand in the long term, in particular in cases where there are capacity bottlenecks in core rail networks. When making investment decisions for long-lasting vehicles, companies should also take the development of driverless vehicles into account. It is not impossible that solo buses will become much less important in future.

5. **Transport companies should work intensively on developing their digital customer interface with an eye to future mobility provision.** New mobility services will be attractive above all when they require no planning before the journey. Such flexible transport can only be offered if individual journey requirements are just as well known as the vehicles’ locations and planned routes. Because of this, the customer interface and intelligent use of data will be of great importance.

6. **Public transport companies should set up pilot projects to gain initial experience with the relevant technologies.** Collective unscheduled transport could already be implemented today, using drivers. This would require the development of complex routing algorithms and customer interfaces but would also provide information about potential demand for later autonomous shuttle services. The deployment of the first driverless shuttle vehicles would provide information about vehicle requirements and how passengers enter and leave the vehicles. In this context there are certainly some cities and situations where cost-effective models are already a possibility, even though drivers are still required to operate the services. It might be a good idea to introduce car sharing or ride sharing services to link up with public transport provision, to test these concepts. Public transport companies with their existing driver and fleet management are in a good position to implement pilot projects of this kind with relatively little extra effort or expense. In addition, data about demand are already available that permit a decision about the kind of provision that might be required.

7. **Public transport companies should network throughout Germany in order to establish unified transport provision in the medium term, and to simplify customer access to the public transport system.** Many private mobility service providers will also offer national or even international fleets. It will be possible to use vehicles in different cities and if necessary, also for long distances, using a single customer access point. Collaboration is important even for pilot projects in order to develop and test the wide range of possibilities and technologies in a coordinated way without too much effort and expense.

8. **During the development and introduction phase of autonomous vehicles and business concepts, it makes sense for mobility service providers and municipalities to collaborate fully.** Depending on strategic decisions, it could also make sense to collaborate long-term with private companies and mobility providers in order to develop specific supporting services.
**Mobility service providers**

1. **Mobility service providers must get ready to enter the market at an early stage.** Even though technological developments do not yet fulfil current expectations, autonomous vehicles will be available in the medium term. As soon as the first driverless vehicles are on the market, they will be put to use very quickly. Mobility service providers must consider whether and how they wish to enter an attractive market where they will however face strong competition. Their customers’ main priority will be the availability of transport options at the time required. The shorter the notice needed before a journey, the more flexible and simpler will it be to use the service. The service will only be really attractive if the fleet is big enough from the start to satisfy the wishes of a large number of customers at short notice. Companies that enter the market is too slowly will lose important market share and customers.

2. **Companies should work intensively to examine the possibility of developing their own shuttle services.** Shuttle services will be an important market. In this context it could also come to competition with public transport companies. It will be important to secure permits for private shuttle transport at an early stage, because this possibility is not envisaged in the current practice of granting permits.

3. **In the end, mobility service providers will have to develop clearly defined services if they wish to establish themselves in the market in the long term.** Analyses of potential and practical tests could give indications of worthwhile services and pricing models. These aspects will be considerably more complex that today’s specialised models for taxis, car hire or car sharing, due to their being implemented over a wide area. In this context there will be a great range of different vehicle sizes and qualities.

4. **Vehicles from several manufacturers should also be integrated in fleets of autonomous cars.** In view of the range of possible applications it is unlikely that a single manufacturer will offer all the specific vehicle concepts that may be desirable. The case-by-case integration of vehicles from different manufacturers will also ensure that the company is not dependent on one supplier.

5. **In the long term, services outside cities and long-distance services could be developed.** When one considers that only about 25 per cent of German cars are registered in large cities, it is clear that there is great potential for new mobility services in non-urban areas.

6. **The value chain must be redefined.** The question of who owns the autonomous vehicles will be of great importance. In addition to mobility service providers and public transport companies, local car hire firms, manufacturers and car dealers will certainly enter the market, and they may be joined by private equity houses and funds. If liability issues become irrelevant for driverless vehicles it may also be easy to hire out private cars.

7. **The necessary elements of robo-taxi or shuttle transport should be developed in good time.** Attention should be paid in particular to user interfaces and customer access, picking up and identifying passengers, routing algorithms and even dynamic fleet management.

8. **We recommend accelerating pilot projects in order to gain experience with this type of service at an early stage.** Companies should also check whether technologies and interfaces are also suitable for possible driverless vehicle services. Public transport companies are also interested in joint pilot projects. The range of preparatory projects in this field is huge. The more solidly comparable services such as car sharing, shuttle transport and taxi services are established and accepted by customers, the faster these services will win through when carried out with driverless vehicles.

9. **When introducing autonomous driving services, the organisational, infrastructural and technological framework in the city must be examined.** Due to differing local conditions and non-uniform permit granting practices, the expense of developing and implementing these services may differ from
city to city. It is likely that in the long term, autonomous vehicle services will be regulated or technologically influenced. Mobility service providers should pay close attention to or participate in the relevant discussions in municipalities.

10. **New services must take road infrastructure capacity into account.** It will not be possible to perform all urban journeys with individually used self-driving vehicles. We cannot assume that additional road space will be provided; that means that in the long term, the limited road network capacity will be a restricting factor. If autonomous mobility services are too successful, they may lead to an increase in road traffic that would then make them unattractive.
Overview of participants

From June to December 2016 we approached experts and sent detailed online questionnaires to over 170 people. The response rate was around 65 per cent, so that over 110 completed questionnaires could be evaluated. The data were collected anonymously. Respondents identified themselves by differences in their professional and industry backgrounds, enabling us to carry out a differentiated examination of the different issues relating to the development of autonomous driving. The respondents belonged to the following four interest groups:

**Vehicle manufacturers and component suppliers** develop and produce vehicles. The important aspect for them is that the vehicles are reliable and attractive for their future users. They are in competition with other manufacturers in this field. This study does not focus on the companies’ strategic direction, but the technological aspects of autonomous vehicles and the demands of vehicle development. The respondents were selected accordingly.

**Public transport companies and mobility service providers** are potential users of the new technology. These companies are not interested in the development of driverless vehicles, but in their use and the effects on today’s and potential future mobility services. We surveyed public transport companies in German cities with over 100,000 inhabitants. The respondents were mostly experts from the public transport companies’ planning departments. We put the following into the category of mobility service providers: companies that currently operate their own fleets, i.e. car sharing providers, car hire companies and companies offering taxi-like services.

Autonomous driving will mainly take place on public roads and therefore within municipalities’ sphere of influence. Municipalities generally are interested in a high-quality, cheap, safe and sustainable transport system, but also bear responsibility for construction and maintenance of necessary infrastructure. Urban road space is a restricted commodity. If traffic conditions change due to autonomous driving, the distribution and use of roads may need to be rebalanced. We surveyed traffic experts from German cities with over 100,000 inhabitants for our study.

In the survey, some general questions were put first to all participants in the same form. This enables us to compare different viewpoints. In addition there were specific questions that take into account the participants’ different contexts. Some of these specific questions applied to several groups and were addressed in comparable form to different participants. For example, the question about the infrastructure required for driverless vehicles is highly significant for both manufacturers and suppliers as well as municipalities. The answers given are not necessarily the agreed opinion of a company or a public authority, but should be understood as individual opinions of the experts we surveyed.

We did not target long-distance coach travel companies in our survey. Due to the limited number of these companies, the possible range of respondents was too small. The future will show whether it is realistic to provide this service in driverless vehicles and whether it really is cheaper. It is possible that a new area of competition could arise for long-distance journeys with driverless, collectively-used cars.

The impact of autonomous driving on logistics was also omitted from this research. The possible impacts and related effects in this field are also complex and specific; they should be dealt with elsewhere. The market potential for autonomous vehicles is obvious, because most goods transport takes place using lorries and the cost of drivers is an important factor. At the same time, there is a great deal of potential for special applications that are suitable in the short-term, such as long-distance motorway routes and transport on factory premises. The question also arises of whether established market structures will start to shift in this field too, and the extent to which logistics concepts could be developed based on smaller vehicles.
Evaluation and presentation

The answers to the questions we put were evaluated for this paper and summarised in diagrams. The presentation mainly makes use of four types of diagram:

1. In most cases the respondent was asked to give an estimate for a characteristic on a scale of one to five (Likert scale). To evaluate the answers, the arithmetic mean was established and shown as a value (Fig. 43). In analysing these diagrams attention should be paid to the fact that a mean value of 3 is equivalent to an average neutral assessment given by respondents.

2. In many cases however the mean value evened out the sometimes very different estimates of respondents. In these cases the proportion of rather positive statements (values 4 and 5) and the rather negative statements (values 1 and 2) were added and set opposite each other. The neutral answers are not shown; they arise from the difference between the rather positive and rather negative values. This makes it easier to show the differences between them.

Fig. 43: Example of diagram type 1 – how do you estimate the costs of autonomous vehicles compared to today’s vehicles

Fig. 44: Example of diagram type 2 – will the introduction of driverless vehicles reduce the obstacles to market entry faced by electrical vehicles?
3. Where respondents were able to select different answers from a list, we show the proportion of all respondents who gave a specific answer. In most cases, multiple answers were possible.

![Bar chart showing different methods to promote autonomous driving]

**Fig. 45: Example for diagram type 3 – how should public authorities promote autonomous driving?**

4. In some cases we asked about percentage values (for example the proportion of autonomous vehicles in a fleet) or year dates. In this case the value shown represents the median of all answers. The median was preferred in this context to the arithmetic mean, because these groups of questions showed some strong outliers.

If the question was put to several respondent groups, the different answers were in most cases contrasted. Only where differences between respondents were small were the answers of all four groups collated.
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