VDV Die Verkehrsunternehmen

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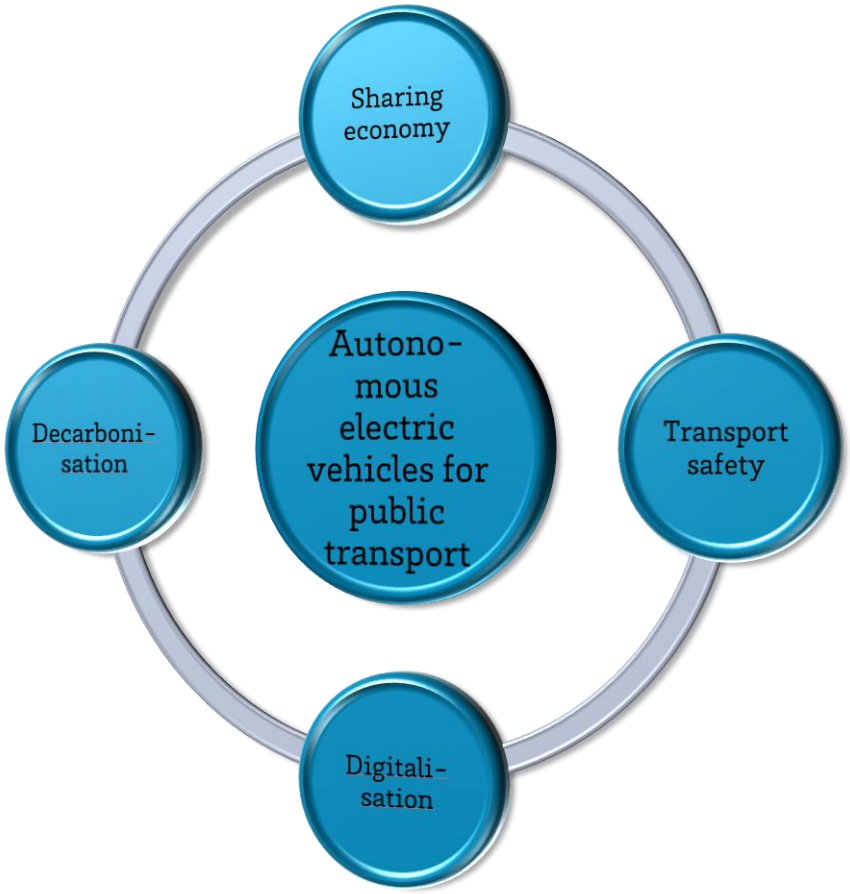
Scenarios for Autonomous Vehicles – Opportunities and Risks for Transport Companies



Imprint

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Summary:

Autonomous vehicles: opportunities and risks for public transport

The development and operation of fully automated, driverless vehicles ("autonomous vehicle") will have a disruptive impact on the transport market and thoroughly mix up the present usage patterns as well as the present ownership and business models. The autonomous vehicle is a game changer, not least because the traditional differences between the various modes of transport become indistinct as an autonomous vehicle can be everything, in principle: a private car, a taxi, a bus, a car-sharing vehicle or a shared taxi.

To express it dramatically: the autonomous vehicle could be part of the public transport system – but it could also seriously threaten the existence of today's public and long-distance transport:

- The autonomous vehicle can threaten the existence of public transport because it makes driving much more attractive. The traveller can phone, sleep or surf online during the trip. When he reaches his destination, he steps out of the vehicle on the front step and it looks for a parking space by itself – or is available to somebody else. It can also be used without a driving licence – and even autonomously bring children to their activities. Thus, public transport loses its present USP (unique selling proposition), i.e. to be transported, no worry about a parking space. Why should anyone then wish to go by bus or rail?
- The autonomous vehicle can be part of the public transport system in the form of a fleet of "robot minibus taxis". This historic opportunity would be a perfect supplement to the present high-capacity public transport. A perfect car-sharing car, which comes to the passenger when he calls it and brings him to his destination. Or a driverless minibus, which can be used to frequently serve bus lines less demanded. Why should anyone wish to buy a private car if he can always call a vehicle when he needs it?

To public transport this means that:

1. all steps towards autonomous driving automatically increase the attractiveness of the private car, i.e. they are counterproductive to public transport to begin with.
2. vehicles driving fully autonomously (but also vehicles that can only drive autonomously on e.g. motorways) put the existing business models of the public transport companies under extreme pressure or even question them entirely. Whereas it may be assumed that high-capacity public transport (urban and suburban rail transportation systems) will also be advantageous in future in respect of performance, travel time and reliability in comparison to autonomous vehicles, e.g. bus transport off the main roads or in medium-sized cities will not have such advantages.
3. only about 1/10 of the present car fleet will probably be needed if autonomous vehicles are operated extensively in cities. Thus, much space now occupied by the stationary traffic could be freed up.
   However, it is fatal that the kilometric performance of cars would increase drastically (i.e. it would more or less be doubled) e.g. because traffic is shifted from public transport to the car: fewer cars, but more automobile traffic – that cannot be an intended development!
4. the shift to fully autonomous driving opens up new opportunities as fully autonomous vehicles can also be operated as part of a public fleet (robot taxis, car sharing etc.) or as part of public transport. Thus, fleets of fully autonomous vehicles can both strengthen public transport and be an alternative to private car ownership. In this way opportunities emerge for sustainable transport concepts that realise extensive mobility with far less vehicles (used efficiently), less automobile traffic and more public transport.
5. fully autonomous vehicles will probably penetrate onto the market via fleet operators and in the form of operation within defined networks. Public transport services, operation within

defined networks and management of fleets are classic tasks of transport companies. Thus, the question arises whether public transport companies shall get actively involved in such systems in collaboration with the public authorities – either as operator, principal, organiser or partner – or whether this field shall be left entirely to private companies without control.

6. not only transport companies have to get active. Transport policy and future public action have to be discussed, i.e. it has to be discussed which development is desired, how transport offers can be integrated and coordinated in a customer-friendly way, and how the general conditions (regulatory policy, financing, etc.) can be modified. Above all, it is important that sharing and fleet operation models are established successfully.

Recommended actions: What has to be done now?

1. It will take about 10-20 years before fully autonomous vehicles are commercially introduced within urban traffic and transport – provided that optimism and development successes continue to go hand in hand. On the one hand, this period is sufficiently long to tackle changes and define the conditions for transport policy. On the other hand, in view of the foreseeable fundamental changes, it is a very short period, which has to be used effectively.
2. **The sector has to actively go into the opportunities and consequences of autonomous vehicles.** The development of autonomous vehicles and the changes caused by that development also include opportunities and risks to the public transport sector. Therefore, it has to go into this development at an early stage, position itself, take advantage of the opportunities and fight risks.
3. Consequently, politics and particularly municipal owners have to be made aware of the consequences to transport policy (even more automobile traffic) and the existential risks, i.e. that public transport companies will only perform the residual transport.
4. From a strategic point of view transport companies and transport associations and/or the entire public transport sector now have to position themselves as integrator of all kinds of mobility offers, link themselves with the customers and offer services to them. The customer relations must be protected via the marketing and CRM measures have to be taken. It is important to plan the transport and investments on a long-term basis and in consideration of the possible impacts of autonomous vehicles on public transport.
5. Already today, opportunities and possibilities of integrating autonomous vehicles into public transport can be demonstrated in model projects, e.g. in the form of operation of autonomous shuttles, which connect remote locations with a rail line or make connections more detailed. First examples of such projects are being realised abroad. In Germany such projects should be initiated now.
6. In addition to these model projects, transport companies and associations should gain experience with the organisation and management of integrated mobility offers in the form of cooperation with other parties offering mobility (car sharing, taxi, bike sharing etc.).

   This scenario necessitates a courageous approach. It could be the answer of the public transport sector to the challenges of digitalisation and the sharing economy and it could simultaneously safeguard the advantages of public transport as regards sustainability, climate protection, decarbonisation, transport safety and quality of life. Shared efficient mobility accessible to the general public is also mobility affordable to the public authorities and the users.

Preliminary remark

Prediction is very difficult, especially about the future.

Inter alia Karl Valentin, Mark Twain, Winston Churchill, Niels Bohr and Kurt Tucholsky are credited with this finding.

Accordingly, it is not possible to predict about the future of mobility and about the future role of autonomous vehicles.

Automated guided systems are already being operated where separate track formations have been secured against entry, but they are not cost-effective everywhere as migration. Driver assistance systems emerge everywhere. Urban bus transport has only seen a few approaches of automation of driving apart from guidance.

This position paper deals with the development of autonomous vehicles, which will mainly be cars, and their impact on public transport.

Why does the Association of German Transport Companies (VDV) position itself with a subject in which it and its members hardly have their own expertise today and for which research and development is performed by universities, automobile manufacturers and their suppliers as well as digitalisation giants like Google and Apple?

The answer is:

Hardly another current innovation has the potential to change our transport systems so radically and dramatically as this one!

The opportunities are so great and risks so big that it seems to be essential to deal basically with this subject and to early develop a strategy that considers all stakeholders.

Available state of development of autonomous vehicles

Only little research on autonomous vehicles is made in public research projects and thus, in principle, accessible. Most information is based on public statements and presentations of groups of affiliated companies. Thus, there is the risk that they only present a desired and optimistic sight of the development in the public.[1] Above all in Germany, this means that the idea of self-driving vehicles is dictated by the automobile manufacturers and set within the context of the use of individual cars.

Developments of the automotive industry

Most classic automobile manufacturers have already commented on autonomous vehicles in public:

- Nissan Executive Vice-President Palmer: "Nissan will make fully autonomous vehicles available to the consumer by 2020."
- Ford CEO Mark Fields: "Fully autonomous vehicles on the market by 2020."
- Jaguar/Land Rover Director of R&D Epple: "Fully autonomous driving will happen within 10 years (= 2024)."
- Daimler CEO Zetsche: "Fully autonomous vehicles that drive without human intervention in the market by 2025."
- Stefan Moser, Head of Product and Technology Communications: "Next generation Audi A8 capable of fully autonomous driving in 2017."
- Volvo wants to operate fully autonomous vehicles on certain routes around Gothenburg in 2017.

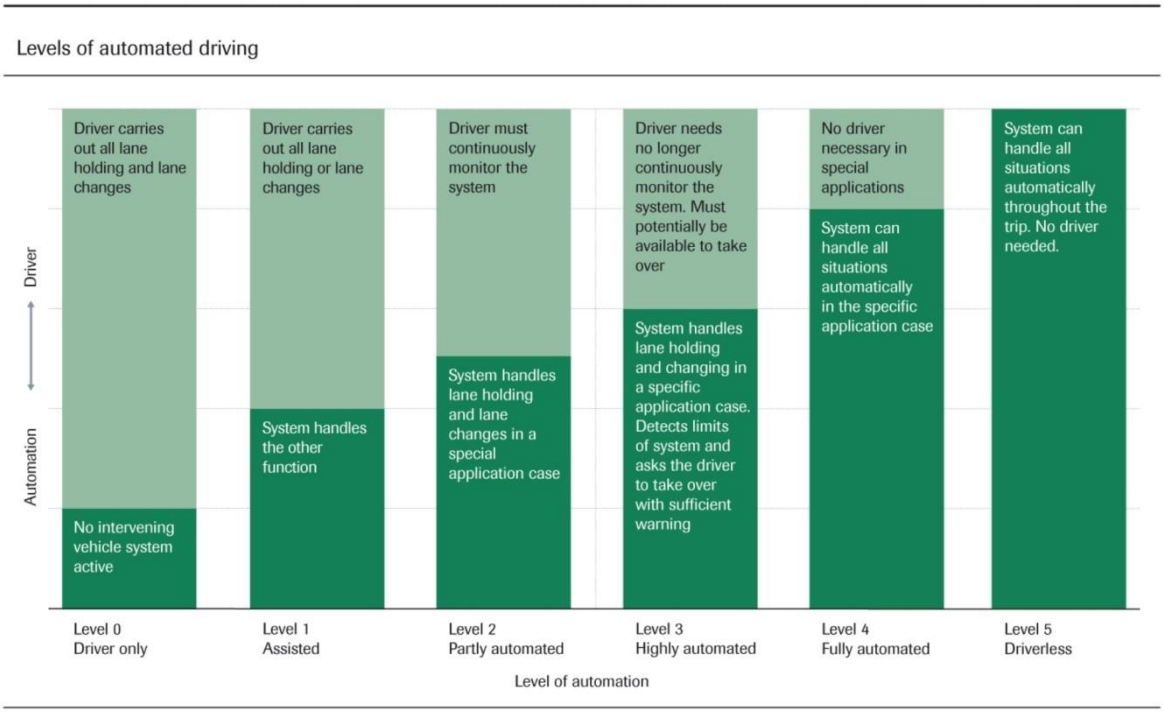
Which value do these optimistic statements of the automotive industry have? It is a fact that

- autonomous operation on lanes without surrounding property (e.g. motorways) with the driver as the fall-back level is state of the art already today and can be performed by premium segment cars. By contrast, no reliable statements have been made about the cost and effort needed for the self-learning, highly complex acquisition and control logic to be implemented for the operation in the cities.
- not until the Vienna Convention on Road Traffic (and thus also the German Road Traffic Regulations and the German Road Traffic Licensing Regulations) are amended, will fully autonomous vehicles be registered. Prior to that, liability issues have to be clarified. It remains to be seen whether the German industry will to push ahead these changes in the end.

The development path selected by the German manufacturers usually begins with the introduction of more services, at first in premium segment cars and then in volume models. According to the German Association of the Automotive Industry (VDA) driver assistance systems will be further developed and sub-functions automated at first, usually in all contexts. Little by little, the cars are automated ever more, until a driverless car has been developed, which can master all situations.

[1] Dr. Alexander Hars, inventivio, provided the authors with some of the contents and sources in his lecture at the 2nd VDV Multimodality Symposium on 29.04. 2015. Moreover, the authors found information in the blog http://www.driverless-future.com/

Figure 1: Levels and terms of automated driving according to the VDA



Source: VDA

According to the levels of automated driving developed by the VDA (See Figure 1) it was at first stated that the established automobile manufacturers did not aim at developing driverless vehicles. However, the statements quoted above and the vehicles meanwhile presented to the public indicate that their objective is indeed a driverless future, although it may be assumed that many automobile manufacturers will also in future stress the joy in active driving.

The "question of ethics", which often comes up, has to be discussed by society in the sense of technical acceptance, but it misses the point. Neither a machine nor a human being can solve the ethical dilemma. The autonomous machine has to observe the law and avoid avoidable damage. If damage occurs because it has become technically and physically inevitable, it is never an ethical fault.

In the near future functions like motorway pilots, park assistants and traffic jam assistants will be applied. Mass operation of partly automated vehicles, which are always also monitored by the drivers, who also have to take control, if necessary, is rather unlikely as it seems to be too risky to rely on the driver to take control. Consequently, the step towards full automation of certain driving situations seems to be inevitable.

It can be anticipated that this development leads to two "disruptive" steps:

1. Inevitably – and probably faster than expected –, it will lead to fully autonomous driving within a defined road network as it is hardly imaginable that the driver has to monitor a system working constantly (e.g. on motorways) and then has to intervene, if necessary. Thus, the system has to function fully autonomously, at least within single road sections.

2. The network of road sections on which autonomous driving is possible will grow steadily. At first, it will comprise the motorways and then – little by little – also the others parts of the road network. Thus, the moment at which it is not only possible to drive

autonomously, i.e. driverless, on single sections, but on the complete route between the point of departure and the destination is getting closer.

Audi, BMW and Daimler's joint purchase of Nokia's digital map service Here indicates the importance of extremely precise maps and the commitment of the automobile manufacturers in the field of autonomous driving.

Highly automated applications for the driving on motorways will make it possible for the traveller to perform other activities. Today only passengers in the car have got this advantage. Subject to the still open-ended legal questions, it seems that automated driving on motorways will be technically possible in a few years. But already this scenario will have considerable consequences to the long-distance and regional transport!

Daimler equips its Future Truck with this technology, which means that it will probably also have an impact on rail freight transport.

In the city several kinds of road users and further factors have to be considered (Google Car CEO Urmson: "Hundred times more difficult"), but a motorway pilot for high speeds also has to be able to quickly detect and calculate potential hazards. Moreover, it seems that the gradual evolution of the assistance systems can hardly be successful as a highly automated (= not permanently monitored) system also has to be able to cope with all unplanned events.[2]

It is indeed a moot point whether the automobile day after tomorrow will be as the Daimler CEOs obviously imagine it with their research vehicle "Mercedes F 015 Luxury in Motion", a 5.22 metre long, nearly three tons heavy, fully equipped vehicle. But the vision is clear: "After all, the Mercedes F 015 Luxury in Motion with its soft leather seats shall not only provide a basis for a relaxed trip to work, but also ensure that the travel time can be used efficiently. Audioconferences, a virtual digression to the wife and the children or a film to clear the mind – it's all possible with the autonomous luxury vehicle". "He who only thinks about technology has not realised how autonomous driving will change our society. The car will not be a mere mode of transport anymore, but a mobile living space", says Daimler's CEO Dieter Zetsche.[3]

Trend researchers even believe that these functions are going to affect the hotel business because business travellers can let their vehicles drive to their destinations by night. A future, which can come true already in 2023 according to TESLA's CEO Musk.

Above all, a development towards autonomous vehicles owned by private persons would result in even more traffic, higher consumption of energy, a higher degree of urban sprawl and increased land take as it would be more attractive to go by car and as the travel time could be used for something else.[4] Such a development cannot be intended! Therefore, it is a matter of urgency to think about other approaches, e.g. operation of autonomous vehicles as feeders to public transport, and about the fleet business. A fleet that consists of autonomously travelling small vehicles operated with electric motors (inclusive of driverless minibuses) within the scope of sharing or robot taxi concepts could be a social benefit.

[2] Cf. Hars: Top misconceptions of autonomous cars and self-driving vehicles

[3] Quotations from Daimler's website, www.Daimler.com, on 22.06.2015

[4] Cf. CARE-North plus: Autonomous vehicles – impacts on mobility of the future

Developments of other manufacturers

It is obvious that the development efforts of the automotive industry were speeded up because other competent stakeholders appeared on the market.

Google's presentation of its autonomous vehicle as a small car without steering wheel was important. Here Google presents itself as technological leader and cooperates with suppliers of the automotive industry like Bosch, Continental and the battery manufacturer LG. At present, they use expensive LIDAR sensors (laser scanners) and high-resolution 3D maps and only drive on known routes. Unknown routes or routes that are difficult to see as well as snow and heavy rain and the interaction with other road users still set limits to the technology.

At present, Google performs long-term tests with about 25 vehicles on highways and in the city. Meanwhile, the fleet has driven nearly two million test kilometres. Google's CEO Brijn expects that Google cars will be operated on public roads in 2018.

Why does Google do so intensive research in this technology? During the time in which a human being actively drives a car, he cannot read information and advertisements on a screen, which should suffice as motivation in view of Google's business model.

Insiders tell that Apple also works on a self-driving car, just as TESLA.

It is very likely that these three companies have sufficient resources to succeed with the development if the automobile manufacturers do not want to take the final step towards the autonomous taxi or if they would lobby a rather restrictive legal framework.

Another group of autonomous vehicles is the autonomous shuttles being operated at low speeds.

A few field tests are being made, e.g.

- Milton-Keynes (GB) with 40 autonomous small cars (Lutz Pathfinder) for two persons, which drive on footpaths at a maximum speed of 12 km/h
- CityMobil2: international research project with autonomous shuttle bus demonstrations in Ostriano and La Rochelle
- Meridian Shuttle in Greenwich (GB) and Singapore
- Easy Mile EZ-10 in Wageningen, Netherlands

These available technologies help to early test the complex situations of interaction in cities.

A project in Ann Arbor (Michigan) in the United States is of particular importance. Under the programmatic name of "Mobility Transformation Center" (MTC) a small test town for autonomous vehicles is being built there. In 2021 the "real-time operation" is to begin in Ann Arbor: "The MTC is a public/private R&D partnership that will lead to a revolution in mobility by developing the foundations for a commercially viable ecosystem of connected and automated vehicles. Such a system has the potential to dramatically improve safety, sustainability, and accessibility. One of the central goals is to develop and implement an advanced system of connected and automated vehicles in Ann Arbor by 2021." *http://mtc.umich.edu/*

However, there are also tests oriented towards public transport, e.g. in Singapore, where autonomous taxis are to be used as feeders for the public transport.
http://www.citylab.com/tech/2015/06/singapore-is-already-planning-for-a-future-of-driverless-taxis/396707/

The development work performed by lateral-entry companies like Google and by niche players like EASYMILE is so interesting because their migration path to the driverless car differs from that of the automotive industry. They do not go the evolutionary way of the classic automobile manufacturers, but begin directly with a driverless vehicle, which can only be operated in non-complex surroundings to begin with. Thereafter, the complexity of the surroundings is increased little by little.[5]

Development trends

Today, it seems that fully autonomous vehicles will be safer than vehicles with a human driver. In the long term insurance companies might consider the advantages of autonomous vehicles, which could increase the acceptance considerably.

The liability issues of relevance to the manufacturers can probably be clarified – if desired by the industry. Of course, the differing economic interests will lead to power struggles.

As it has already been described, there is the idea of the self-driving, private luxury limousine, which is used as bedroom, living room and office on wheels and on roads. Such vehicles are heavy and therefore energy-intensive – also if they are operated electrically.

Such a development would lead to further urban sprawl and longer travel times or traffic jams, which would hardly be regarded as disadvantageous by the travellers because they use their time meaningfully. However, from an ecological point of view this scenario would need too much space, too many resources and too much energy. Consequently, such a development does not harmonise with the climate targets and the objective of sustainability of the Federal Republic of Germany and its municipalities.

Another development is the fully autonomous special-purpose vehicles, which can particularly be used as "driverless taxis" for individuals, small groups and luggage transport within urban and regional transport in the form of robot taxis, car-sharing swarms or driverless minibuses.

Due to their higher degree of safety – and perhaps a lower maximum speed – such vehicles can be manufactured at less weight, in smaller sizes and with less motorisation, which would in turn increase the energy efficiency and allow electric mobility.

(Perspectively,) such vehicles are
- safe,
- electric (i.e. they can be fed by regenerative sources of energy),
- quiet,
- less expensive, and
- more space-efficient than the present vehicles.

Thus, they are a great challenge to the present advantages of public transport.

In his book "The Mobility Revolution" Lukas Neckermann mentions three driving forces that lead to this revolution:

Zero emissions The necessity of developing the transport sector into a sector without local and climate-damaging emissions.

[5] Cf. Automated and autonomous driving – Regulation under uncertainty; OECD

Zero accidents The necessity of organising the transport sector so that no accidents at all are caused by human beings.

Zero ownership The adoption of the sharing economy by the transport sector to increase the efficiency of the resources substantially.

A very important development trend is the function as "shared" vehicle within the scope of the sharing economy. Due to the autonomous vehicles taxis, ride sharing, car sharing and part of public transport will tend to have the same fields of operation. In the long term, car-sharing swarms and robot taxis will merge to one mobility offer.

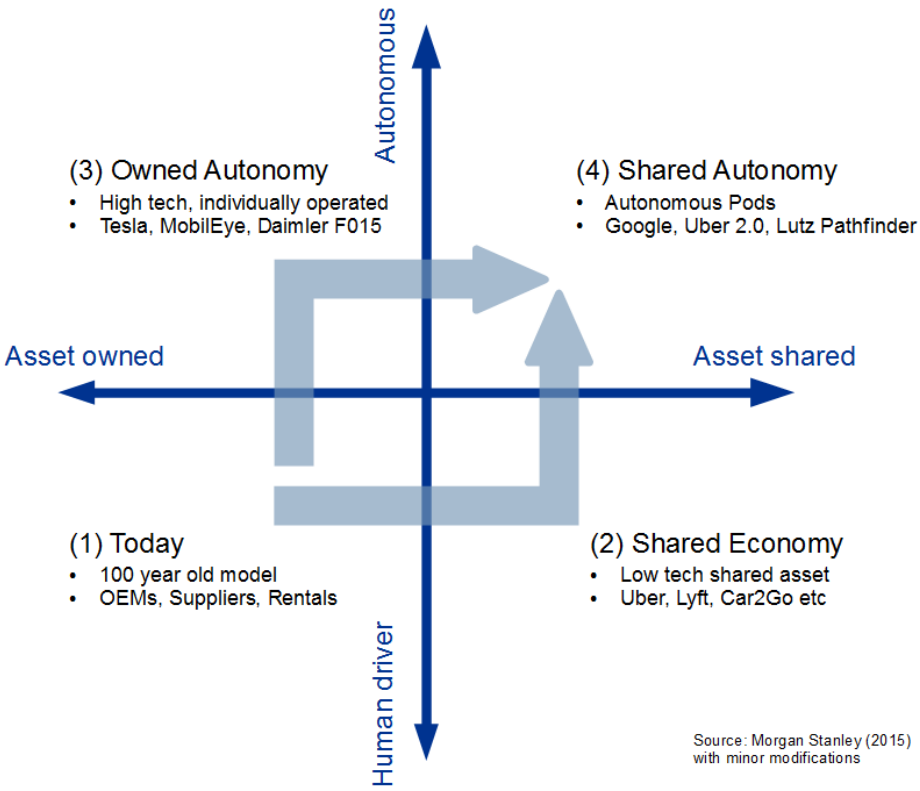
In Helsinki some city planners pursue such a vision: "The participants will only enter their position and their destination as well as a few preferences into their mobile phones. Then a mobile app, which considers all modes of transport from autonomous vehicles to minibuses, city bicycles and ferries in a single mobility offer, will be used as the planning and payment tool."

Already today, minibuses are operated as shared taxis in Helsinki. This new service, which is called "Kutsuplus", can be ordered via the mobile phone. The passengers are picked up and the route depends on their destinations. Such a trip only costs half as much as a taxi trip, i.e. it is still more expensive than public transport, but this might change when more vehicles are put into operation. Kutsuplus does not compete with the available buses and the metro, it supplements them.

According to Morgan Stanley the shared economy will also influence the development of the future mobility system considerably. Not only will shared economy influence the development of autonomous driving, car sharing and ride sharing will also result in autonomous pods with small vehicles developed for special purposes. Morgan Stanley believes that this vision will be reality in 2023 – 2026.[6]

6 Morgan Stanley: "Autonomous Cars: The Future Is Now", Jan 23, 2015

Figure 2: Mobility development trends with shared autonomy according to Morgan Stanley[7]



Such autonomous vehicles that everybody can afford and that (partly) fulfil the needs for daily mobility have further advantages to society:

- they ensure the mobility of people with reduced mobility (e.g. reduced vision, reduced physical mobility);
- they ensure the mobility of people without driving licences (children, young people, seniors) as they can travel autonomously without involving another person;
- the time spent in the vehicle can be used for other tasks than driving it.

All these effects lead to a social benefit and can increase productivity.

The higher level of safety of fully autonomous vehicles will probably reduce the insurance premiums. Shared autonomous vehicles have a more favourable cost structure, at least per kilometre, on the mass market than private cars and traditional taxis. Thus, cost arguments might decrease the "joy in driving".

Tipping point: fully autonomous driving

All technological developments towards autonomous driving (automatic driving on the motorway, automatic parking away from the destination etc.) increase the attractiveness of the car: car driving gets even simpler, more time-saving and more relaxed. These developments are extremely desirable to car drivers – and are therefore pushed immensely by the car-driving

[7] Morgan Stanley Research, LA Times, cited by Hars in LA Times.

customer! However, to public transport they are directly counterproductive because it is increasingly robbed of its unique selling proposition (USP), i.e. to be transported, no worry about a parking space, etc.. This also applies to society because higher attractiveness of the private car means that people will go even more by car.

Only when the technological transition to fully autonomous driving succeeds, will there be new opportunities all of a sudden, which make it possible to change the ownership structures and the usage patterns because fully autonomous vehicles cannot only be used as private, driverless cars, but also within public fleets (robot taxis, car sharing) or within public transport (autonomous feeder, autonomous line-service transport). Fleets of fully autonomous vehicles might also strengthen public transport and be an alternative to the private car.

Just the development pursued by Google clearly indicates the intention of operating autonomous vehicles within the scope of public fleets. On the one hand, the small "Google cars" have deliberately been designed as short-distance vehicles for local transport and low speeds, i.e. they are obviously no alternative to a private all-purpose car. On the other hand, Google is heavily involved in the transportation network company Uber, which might take on the fleet operator function for e.g. "robot taxis". It remains to be seen whether the Uber mentality of licence-free taxis will be considered in the German Law on Passenger Transport and whether the swarm taxi will be defined as a taxi or as public transport.

Two extreme scenarios thought out show that the development could not differ more:

We shall either see that the innovation of autonomous driving will lead to total focussing on the private car as private transport and thus to the slow death of public transport

or

we shall see that the autonomous car will be fully integrated into a public transport system, which covers all streets in the city, all commuter relations and all long-distance transport so that it makes the private car superfluous.

Scenario A: The total car society

- Private cars drive (fully or rather) autonomously. The consequence: The travel time can be used, there are no parking space problems and no costs for parking and children are brought to the nursery school by car. Even more automobile traffic!

- Fleet operators offer low-priced robot (shared) taxis and attack the USP of the classic public transport.

- Road capacities are utilised more intensively so that there is room for even more cars on the roads.

- Public transport gets under massive pressure. High-capacity public transport is still operated in big cities/metropolises (because it is still advantageous as against private automobile traffic in respect of the price and the travel time), but weaker lines (buses, small towns, in the evening, at the weekend) are "dead" or pure "residual transport" for the famous "A-groups", which cannot afford shared taxis.

- Urban sprawl, fully car-friendly structures (you can drive everywhere). It is not possible to free up public spaces – contrary to consequent multimodal mobility based on public transport.

- Hardly pedestrian traffic anymore (you enter and leave your car at your house door).
- Massive pressure of the automotive industry to sell and use vehicles (it wants to sell cars).

Scenario B: Triumph of public transport

- Public transport is the backbone of transport.
- Some public transport is performed by way of autonomous vehicles (rail, bus lines with standard buses or minibuses); it is highly attractive and very frequent.
- In rural areas with little bundled demand autonomous vehicles increase mobility and social participation.
- The public transport system is graduated: basic (reasonable prices for line-service transport), plus (medium-priced shared taxi), premium (non-shared taxi).
- Together with public transport companies fleet operators offer robot taxis and/or car sharing as feeders or as supplement to public transport and as "premium public transport offers".
- Public transport companies and other companies offer connected mobility.
- The majority of the inhabitants do without their own cars – because they do not need them anymore or because the alternatives are much more attractive.
- Parking spaces and roads will be freed up massively and can be used otherwise in the city, which is environmentally friendly and increases the quality of life of the inhabitants.
- The price models lead to cost transparency and incentives to shift to efficient modes of transport (i.e. prevent that everybody go by non-shared taxi in the peak traffic hours).

Imaginable usage models of autonomous vehicles

Simulation results of various usage models of autonomous vehicles

Scenarios for the operation of fleets of autonomous vehicles that can be booked in public have already been calculated for several cities, sometimes with and sometimes without upholding of high-capacity public transport for heavy traffic.

The most extensive and up-to-date calculations have been made by the International Transport Forum at the OECD[8] using the example of Lisbon. Two different scenarios were examined in this report:

- Autonomous vehicles as ride-sharing vehicles (taxi robot system); here travellers share time and space resources by travelling in the same car simultaneously up to the capacity limit of the vehicle; and
- autonomous vehicles as a car-sharing fleet; here travellers share time resources by travelling in the same car sequentially (car-sharing swarm).
- Both scenarios were examined as scenarios with a 100 % and 50 % shared autonomous fleet; it was assumed that the remaining motorised trips are performed by private cars.
- All cases were examined with and without upholding or development of the high-capacity public transport (metro, tram, BRT) with closing down of the bus transport.

Table 1: Results of the simulations, source of the data: International Transport Forum

Scenario			Public transport mode share [%]	Car mode share [%]	Weekday travel volumes in car-km [%]	Peak-hour travel volumes in car-km [%]	Maximum number of parked vehicles [%]
Baseline (=100% in comparison)			15	100	100	100	100
100% shared autonomous fleet	Ride sharing	No high-capacity public transport	0	12.8	122.4	125.3	7.2
		With high-capacity public transport	22	10.4	106.4	108.8	5.6
	Car sharing	No high-capacity public transport	0	22.8	189.4	203.2	16.0
		With high-capacity public transport	22	16.8	144.3	154.6	10.7
50% private car use for motorised trips	Ride sharing	No high-capacity public transport	0	102.4	160.2	167.5	99.4
		With high-capacity public transport	22	78.2	129.8	135.8	75.8
	Car sharing	No high-capacity public transport	0	107.0	190.9	197.0	103.8
		With high-capacity public transport	22	82.0	150.9	155.7	78.8

[8] International Transport Forum CPB, Urban Mobility System Upgrade, Paris 2015 – www.international transportforum.org

Table 2: Results of the simulations, source of the data: International Transport Forum

Scenario			Cars travelling at peak hours [%]	Share of idle time of cars [%]	Share of cars for 1-2 pass. [%]	Share of cars for 3-5 pass. [%]	Share of cars for 5-8 pass. [%]
Baseline (=100% in comparison)			100	96			
100% shared autonomous fleet	Ride sharing	No high-capacity public transport	43.1	27.1	34.4	60.3	5.3
		With high-capacity public transport	35.2	27.2	35.2	58.7	6.1
	Car sharing	No high-capacity public transport	76.7	39.3	100	0	0
		With high-capacity public transport	56.6	35.2	100	0	0
50% private car use for motorised trips	Ride sharing	No high-capacity public transport	117.8	22.8	31.8	48.5	19.7
		With high-capacity public transport	90.9	23.6	33.6	47.1	19.3
	Car sharing	No high-capacity public transport	133.6	39.4	100	0	0
		With high-capacity public transport	103.4	38.6	100	0	0

The calculated scenarios show some remarkable results (some of the findings derived from these results are printed in bold below):

- The scenarios in which the private car is replaced 100 % show that traffic can be handled by a fleet that is 4 to 10 times smaller than the present fleet.

- The spaces in the cities presently used for parking of the vehicles would be freed up even more.

  - **Fleets of autonomous vehicles could lead to less traffic with fewer resources.**

    - **The space freed from motorised private transport can be actively used for other purposes.**

    - **Fleets of autonomous vehicles only have a chance if they are energy-efficient and low-emission.**

    - **The automobile manufacturers would have to develop fully new products and business models.**

- All scenarios without public transport would increase automobile traffic by 25 % to 110 %. These high values are definitely not acceptable to cities.

  - **Fleets of autonomous vehicles definitely need high-capacity public transport as their backbone.**

- **From the point of view of the climate change policy it would definitely be wrong to introduce autonomous vehicles without increasing their energy-efficiency or without using renewable energy sources.**

- **The road capacity would increase by 40 % in the city and by up to 80 % on the motorways if (only) autonomous vehicles are operated as the time gaps and the starting time at light signal installations would be shorter[9]. Thus, the growing road traffic volumes seem to be "ridable" – with high-capacity public transport. However, the transition period remains critical.**

- The mode share of public transport would increase from 15 % to 22 % if the buses are replaced as assumed; the high-capacity public transport would be about doubled.

  - **The high-capacity public transport as the backbone definitely has to be significantly developed.**

- The ride-sharing concepts, in which a traveller shares the vehicle with up to 7 travellers, lead to less automobile traffic. As many places will be without area-wide bus transport, there will be more traffic (in Lisbon the buses account for 25 % of the public transport).

- However, boarding and alighting have to be foreseen in ride-sharing concepts. On average, they generate about 40 % detour trips and increase the travel time by about 30 %. Nevertheless, the average travel times in the ride-sharing scenarios are only longer than that of the private car in the transition scenario. In the car-sharing scenarios the travel time is reduced by 31.1 % to 37.9 %. The waiting times for the autonomous vehicles are relatively short (3-5 minutes).

- The transition scenarios (without bus) indicate that the traffic would be very heavy in the transition period.

  - **The bus – perhaps in the form a self-driving (electric) minibus – is also relevant in the scenarios.**

  - **Generally, the mix with private cars produces poorer results.**

    - **Therefore, the transition period should be relatively short.**

    - **Public transport has to be extended and developed beforehand.**

    - **The advantages of using autonomous vehicles are not obvious everywhere in the transition period and should be politically supported.**

    - **High parking fees at the point of departure and at the destination can increase the number of shared vehicles considerably.**

Of course, these scenarios still have some weaknesses. As they cannot be fully transferred to big and medium-sized cities in Germany, it seems desirable or necessary to explore, model and calculate scenarios for such cities.

Especially scenarios in which car-sharing swarms, robot taxis and self-driving minibuses are mixed should be examined. The acceptance of ride sharing as mainstream seems to be a rather

[9] Friedrich, B. in Lenz, B. et all (publisher) Autonomes Fahren, Springer, 2015

extreme assumption. Here, too, there would probably be a willingness to pay for individual transportation due to the efficiency advantages (time saved as no passenger enters, no detour trips). Boarding and alighting as well as the efficient allocation of passengers to the ride-sharing vehicle (e.g. at a metro terminal after the arrival of a metro train) also have to be discussed in detail. In this connection it also has to be born in mind that one of the biggest problems of autonomous vehicles is the many pedestrians / people walking on the road.

Furthermore, the roles of the non-motorised transport and of the future electric, "single-lane" vehicles were not detailed sufficiently in these scenarios.

It is unlikely that Germany with its grown urban structures and the private investments undertaken in its public and private transport systems will be the "mobility revolution" pioneer. It might first take place in the fast-growing Asian cities, which look for new solutions. However, the necessity of sustainable transport solutions will also lead to reorganisation of transport in European cities.

Autonomous vehicles as part of public transport

The autonomous vehicles already performing test shuttle transport of passengers, the so-called self-driving minibuses, indicate which further possibilities of operation might possibly be realisable for public transport with autonomous vehicles in the near future. However, not only the possibilities of automating the present public transport vehicles (metro vehicles, tramcars and buses) should be considered.

The present autonomous shuttles are still in the test phase and can only be operated within a defined area at low speed or within their own infrastructure. Nevertheless, valuable experience has already been gained with these vehicles, which could be helpful for faster introduction of autonomous public transport vehicles at a later stage.

For the general identification of possible options of autonomous vehicles within public transport it is assumed that fully autonomous vehicles are available.

The possible options comprise[10]

- efficient development of cosmopolitan residential areas or industrial estates as well as university campuses by way of autonomous, driverless, on-demand or line-service shuttles;

- replacement of Park & Ride and Kiss & Ride by autonomous vehicles as feeders and connectors within an intermodal mobility chain, in which public transport is the main mode of transport;

- disperse origin and destination transportation services with autonomous pay-as-you-go offers. The present "alternative kinds of service" are then identical with the concept of autonomous car and ride sharing;

- individualisation of the public transport offer by way of autonomous (small) vehicles – in line with car sharing with valet parking or autonomous taxis;

[10] Cf. also Lenz, B. in Lenz, B (published) Autonomes Fahren, Springer, 2015

- a more flexible public transport offer by increasing the capacity with further autonomous vehicle units;

- increase in the availability of public transport offers in rural areas, on less demanded routes or outside the usual public transport times;

- increase in the demand for public transport by mobilising people who cannot drive cars;

- transport of pupils in small vehicles, which would be possible if the procurement and energy costs per passenger kilometre and not the staff costs or the availability of drivers would decide the number of vehicles needed for the transport of pupils, which would also reduce the travel times.

These approaches all have the following in common:

- they apply to public transport areas that are characterised by little demand and relatively high staff costs today;

- driverless public transport vehicles are monitored by a control room, which the passengers can always contact;

- the entire information, booking and accounting flow is based on mobile terminal units and has to consider all modes of transport.

B. Lenz points out that the availability of an autonomous 24/7 public transport offer for anyone might not only advance the pay-as-you-ride settlement, but also the idea of a general "public transport tax".[11]

If transport companies do not themselves raise the question of autonomous vehicles in the form of scenarios, local politics might be motivated by providers of automotive mobility services to take up or allow the subject, which would not be a chance for public transport, but competition to the present service concepts.

In contrast, it is important to early signalise to the competent authorities that the present public transport companies are also the right partners to advance autonomous public transport. It might be an idea to include experimental clauses in long-term contracts.

Autonomous shuttles operated on defined routes within the scope of a public transport offer can be realised much earlier than autonomous universal vehicles, which could be a first mover advantage with a positive symbolic power for public transport.

[11] Lenz, B. in Lenz, B (publisher) Autonomes Fahren, Springer, 2015

Opportunities and risks for public transport

Autonomous vehicles will probably be technically available and legally deployable in a not too distant future. They will probably be very safe, electric, affordable, quiet and low-emission. To begin with, these vehicles make up a risk as they can compete directly with public transport.

There is especially also the risk of "political" competition about innovations, attention and promotional funds and – at the municipal level – about areas, priority lanes or price fixing.

Usually, cities do not have effective business models for sustainable reconstruction or for the preservation and expansion of their infrastructure. In future, transport-related taxes and takings will be important.

We have to ensure fair and purposive general conditions together with the public authorities. This means that

- everybody providing sustainable transport has to be supported;
- counterproductive offers leading to even more automobile traffic and urban sprawl have to be prevented.

The development of electric mobility must also be judged by this development. It is only meaningful with further regenerative energy and rather as a fleet vehicle or electric bus than as a private car. Individual promotion of electric cars would make car driving more attractive and lead to even more traffic jams.

Municipal transport companies sometimes suffer disadvantages as regards adventurousness, pace or rigid general conditions like the wage level or lack of capital. However, due to their – often municipal – owners they also have the advantage of being the desired, non-profit making, local mobility provider.

Therefore, it is important to inform about the existential risks that emerge when public transport companies are condemned to only perform residual transport. Private traffic without public transport as a cost-effective alternative would be much more expensive.

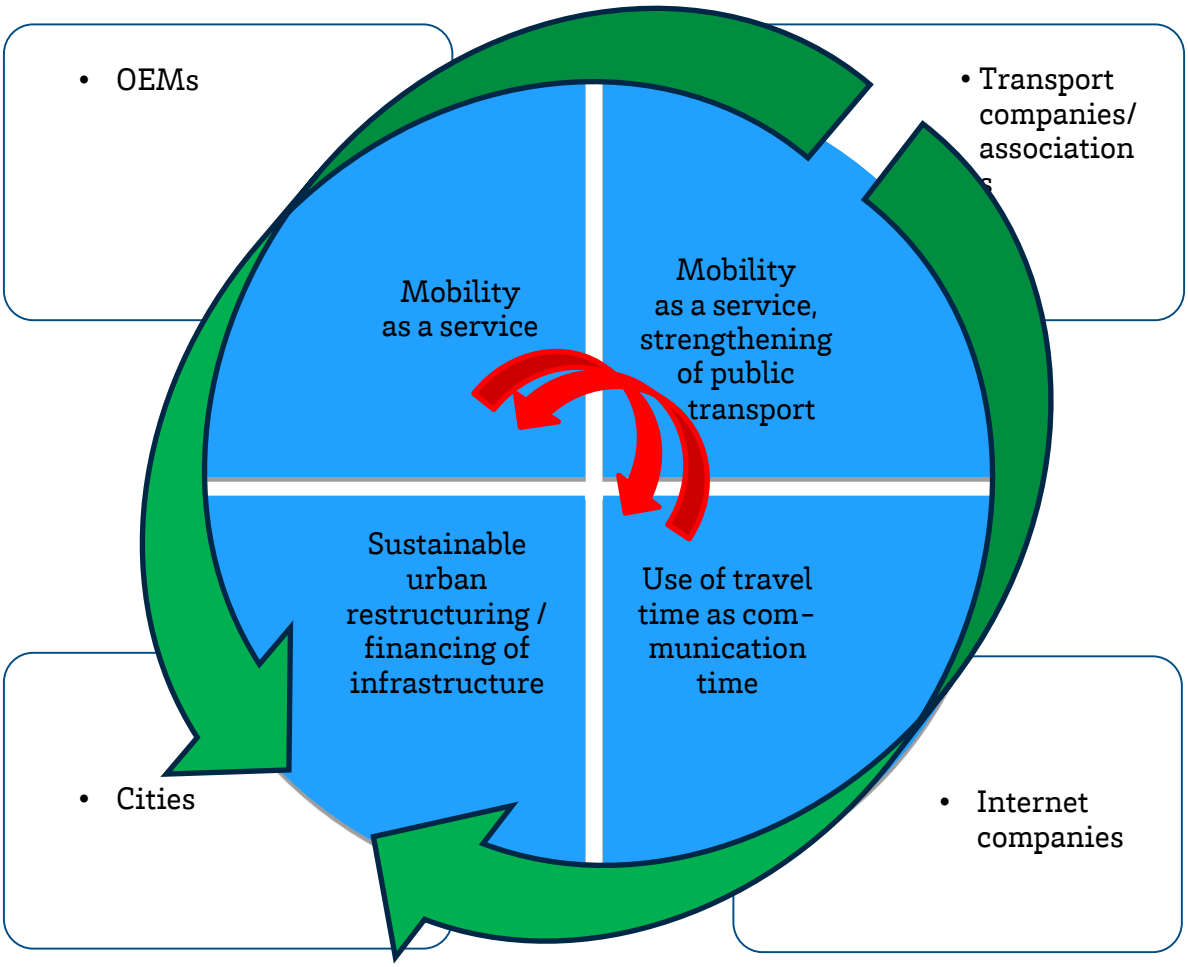
It will be a challenge to actively integrate autonomous vehicles into public transport. If they are introduced within the scope of sharing economy, they can become part of a public transport system. At first, the alarm bells ring because the scenarios show that – in terms of figures – the present public transport system could be fully replaced by just 2.5 % more autonomous vehicles (compared with the present state and by 25 % more autonomous vehicles compared with the objective) provided that a 100% shared autonomous fleet is introduced and that the mode share of high-capacity public transport amounts to 22 %. However, it is a purely theoretical situation because the migration path is dependent on the development of the high-capacity public transport. Moreover, it has to be borne in mind that the number of private car trips would increase drastically (or even be doubled), which would have negative consequences to the urban compatibility of the autonomous vehicles and to the road maintenance.

The strategic objectives of the automobile manufacturers and the internet companies, on the one hand, and the public transport companies and the cities, on the other hand, appear from the below chart.

In this scenario the automobile manufacturers (OEMs) would sell less than 20 % of the number of vehicles that they sell today. Therefore, many automobile manufacturers already now plan to include "mobility as a service" in their range of services.

Internet companies pursue business models based on usage data, desired contents, services, advertisements and technical integration. They want to ensure that the travel time is used as communication time and they want to learn something about the users' ways and routines.

Figure 3: Market stakeholders and possible strategies in connection with the introduction of autonomous vehicles



Thus, the automobile manufacturers also want the data about users and usage, i.e. they enter the business field of the internet companies. In contrast, the internet companies develop mobility services and enter the business field of the automobile manufacturers (red arrows). Neither looks to the common good of the cities or public transport.

Only when the transport operators initiate strategies and involve the cities (green arrows), will sustainable urban restructuring of the transport infrastructure and its financing be possible and intended. The other stakeholders do not always strive for a shift in the transport modes and for a city in which it is worth living.

As the trips will be planned and registered via smartphone apps and mobility platforms (further e.g. manned ways of access will handle the booking wishes and settle the accounts on the same platform), the one who operates the mobility platform and possesses the customer data will control the market.

That is the chance of the transport companies, which now have the

- most successful smartphone apps for public transport and/or mobility platforms and ITCS as well as

- the biggest basis of known customers.

The OEMs and the internet companies, which can pursue exactly this strategy, have the advantage of more available resources.

Already today public transport is regarded as the backbone of multimodal mobility. The transport companies and associations strive for the role as integrator of supplementary mobility offers and have begun to play this role. Due to the interconnection of bus and rail transport systems with car sharing, bike sharing and ride sharing public transport can already now play an important role on the growing "mobility as a service" market. This development towards the all-inclusive mobility service provider is necessary if the transport companies and associations want to assume the decisive position in the market – also at the transition to autonomous vehicles – despite less financial resources than other companies. At present, their market shares are based on their regular customers (about 10 – 15 % of the inhabitants) and their occasional customers (about 25 – 35 %), which they can increase in areas in which they already develop a broader market basis with their own multimodal offers or with their own platforms for such offers.

In a competitive world the transport companies and associations would only receive the customer data for the offers that they themselves perform or order, which leads to the question whether the transport companies should also deal with autonomous vehicles (on behalf of the municipalities as the owners and competent authorities).

Transport companies and associations have the competences needed for this task; they already integrate many different kinds of offers. The core business of transport companies is exactly the management of vehicle fleets. Moreover, they often have many years of experience with electric mobility.

The transport companies and associations should control the planning process and the transition process so that autonomous vehicles become a supplement and not a threat to public transport. As the transport companies are hardly going to push the technical development of cars, they should also consider possibilities of cooperation. The earlier, the better the opportunity will be to reach strategic positions.

Conclusions

At present, the image of autonomous driving is formed by the big automobile manufacturers. The general public considers autonomous cars to be rather unimportant in the context of public transport. However, it is important to put autonomous vehicles into the context of public transport because they offer some opportunities to public transport if they are integrated meaningfully.

It is important that transport companies and associations as well as districts, cities and municipalities, which are the competent authorities and owners of the transport companies or traffic planners, deal with the impacts that autonomous vehicles – in the form of fully automated transport systems, the services of which can be fetched by the users – might have on public transport.

The development towards autonomous driving will automatically increase the attractiveness of private cars and is therefore at first counterproductive to public transport. However, fully autonomous driving also opens up new opportunities all of a sudden as fully autonomous vehicles can also be operated as part of a public fleet (robot taxis, car sharing etc.) or as part of public transport. Consequently, fully autonomous fleets could strengthen public transport, on the one hand, and be an alternative to owning a private car, on the other hand. Thus, it will be possible to develop sustainable transport concepts, which realise extensive mobility with far fewer cars (used more efficiently), less automobile traffic and more public transport.

Fleets of autonomous vehicles definitely need the high-capacity public transport as their backbone. From the point of view of the climate change policy it would be wrong to introduce autonomous vehicles without increasing the energy efficiency and without using renewable energy sources. Being the backbone, it is inevitable to develop high-capacity public transport massively.

Besides the activities of the transport companies and associations it is important to take a discussion about transport policy and to define the role of the public authorities: Which developments are desired? How can transport offers be integrated and harmonised in a customer-friendly way? How do the general conditions (regulatory policy, financing etc.) have to be modified? Above all, it is important to succeed in establishing sharing models and fleet operation models.

The advantages of using autonomous vehicles are not obvious everywhere in the transition period and should be politically supported. High parking fees at the point of departure and at the destination can increase the number of shared vehicles considerably. Beforehand, public transport has to be extended and developed, particularly in the high-capacity areas, in the form of segregated or independent rail and bus transport systems. Autonomous vehicles should be realised at an early stage in the outskirts of the cities and in rural areas as feeders and connectors to bundled public transport. Suitable areas of operation have to be identified and the first pilot projects have to be realised.

It will probably take about 10-20 years before fully autonomous vehicles are commercially introduced within urban traffic and transport. Generally, the mix with private cars produces poorer results. Therefore, the transition period should be relatively short.

From a strategic point of view not only the transport companies and associations, but the entire public transport sector have to:

- become the integrator of mobility services;

- develop and operate interoperable mobility platforms;
- protect their customer relations and apply CRM measures;
- offer "mobility as a service";
- increase their market shares;
- network themselves with the customers and offer services to them;
- speed up the transition to renewable energy sources;
- dare to experiment with autonomous shuttles;
- speed up the degree of automation of their own offers;
- make long-term transport planning and investments in consideration of the possible impacts of autonomous vehicles on public transport;
- make the stakeholders sensitive to the opportunities and risks as well as to the importance of autonomous vehicles from the point of view of transport policy.

This scenario is the answer of the public transport sector to the challenges of digitalisation and sharing economy and safeguards the advantages of public transport in respect of sustainability, climate protection, decarbonisation, transport safety and quality of life. Public transport is the high-capacity backbone of multimodal mobility. Shared, efficient mobility accessible to the general public is also mobility affordable to the public authorities and the users.

Integrated mobility managed by public transport companies ensures that the objectives of the cities and the objective of public welfare are integral parts of the strategy.

Autonomous vehicles should be brought on the market as part and innovation of public transport.