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The introduction of automated vehicles and its implications for society and the environment

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Abstract

The findings in this paper show the big potential contributions of automated cars to improvements of the ecologic situation and social inclusion in the mobility market. These potential effects are however dependent on the future use cases of this new technology and will only materialise if implemented as shared mobility. Based on today's mobility behaviour, the number of vehicles will be reduced up to -80% if cars are shared, and up to -90% if rides are shared as well. Analysing existing sharing initiatives, the implementation of shared automated mobility can be seen ambivalently. On the one hand, a missing driver has some disadvantages as she/he plays an important role if accompanying specific user groups such as the disabled, elderly or children. On the other hand, the system would be much more efficient as cars are not sitting idle being parked at places not accessible to the next client. In the absence of shared mobility models, there is a high risk of an increase of private car use as new user groups are included, and as the convenience of traveling will increase in general through automated cars.

Keywords: automated vehicles, flexible transport, sharing mobility, car sharing, carpooling, demand responsive transport

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1. Introduction

Within the vast areas of technological innovations today, the development of automated vehicles receives special recognition by companies and the public alike. Despite the many challenges still lying ahead of us, there is a consensus that automated vehicles will arrive as a mass product at one point - the only question being when this will happen. But while a lot of resources go into the technological development, and the public debate is focused on ethical questions and human-machine interactions, research on the broader consequences on society and the environment is still limited. With this paper, based on the findings of our completed research project "Shared Autonomy" funded by the Austrian Ministry for Transport, Innovation and Technology (bmvit), we want to fill this gap and address the following issues: a) ecological factors such as implications for emissions, and traffic volume, and b) social factors such as access to mobility services, and mobility behaviour. Our main focus rests on rural and suburban areas where the introduction of automated vehicles is expected to have a big impact due to the current predominance of a singular mobility mode—the privately owned car, and the lack of alternative options.

Our main working thesis is that there are several scenarios possible on how automated vehicles will be used in the future, ranging from individual to (synchronically or diachronically) shared models, and each of these having different effects on the environmental indicators. If self-driving vehicles are to be environmentally friendly, it is less a question of technological development but instead of the willingness and the capabilities of people to share them. This again, is dependent on social and organizational innovations that facilitate such sharing.

In our research we analysed vast mobility data and then calculated the above mentioned environmental factors based on the different scenarios, plus doing field research studies of where automated buses are already put into practice as well as where new types of shared mobility services are currently being implemented. Our results indicate big differences between the three scenarios as far as the ecological indicators are concerned, and also show that "mobility" is much more than just traveling from one location to the other. Whereas having your own car used to represent freedom and autonomy, mobility based on sharing and co-creation models could imply feelings of community and belonging, by providing people a platform for getting to know, interacting with and caring for each other. Members, then, would not only become more mobile, but also feel safe, and more connected to their communities. At first sight, self-driving vehicles appear as undermining such a culture of collaboration and trust. If a car can drive without the need of a driver, self-organization seems redundant. But at the same time, such a culture is needed to redeem the promises of self-driving technology and secure its environmental effects.

2. Trends in vehicle automation

There are two trends to be observed when talking about the development of automated cars. Firstly, the continuous and stepwise evolution of conventional cars towards automated vehicles usually carried out by existing car manufacturers in cooperation with IT companies. Secondly, the development of smart shuttles, which are fully automated and the use case is focusing on shared usage of the vehicle. Most of these manufacturers have a vision of a mobility revolution in mind, which will completely change road traffic as we know it today. One of the main projects following this path was the European research project CityMobil2 (Sessa et al. 2015) and its predecessors. Meanwhile there are existing manufacturers offering such vehicle types, such as EasyMile EZ10, Navya Arma (see figure 1) or Olli from Local Motors. Most of them are in prototype phase with still a lot of need for testing the reliability of the vehicles in everyday traffic.

Because use cases similar to conventional public transport supply have predefined routes or service areas and the vehicles mentioned above basically follow "virtual rails", their technological implementation is less complex than that of the privately used automated car that has to be capable of dealing with varied environments. This potentially enables an advantage in development. On the other side, the financial resources are unevenly distributed, a potential lever for transport policy intervention. Test cases of smart automated shuttles are operated in several areas already, among others in the rural area of Koppl, province of Salzburg, Austria (www.digibus.at) or the city of Sion, Switzerland (https://www.postauto.ch/de/smartshuttle). Many more pilot tests are already planned and implemented all over the world, an overview can be found at www.sharedautomatedmobility.org.

Fig. 1 The Navya Arma automated smart shuttle, Photo: Roman Klementschitz

3. Sharing vehicles and mobility

If, within the context of automated vehicles, mobility ought to be more environmentally sustainable in the future, besides alternative propulsion systems the principle of sharing vehicles is an important issue. Considering the high purchase costs of automated vehicles especially in their initial phase of entering the mobility market, there will also be a financial argument for sharing.

3.1. The sharing market for mobility

Automation will simplify a lot of current use cases for sharing mobility. Therefore experts expect a decrease of the number of privately owned and exclusively used cars (e. g. OECD 2015, Berylls Strategy Advisors. 2017). The differences of the current use cases within shared mobility will have mostly dissolved because of the introduction of automated cars (see table 1). Additionally, some use cases, which are restricted to urban areas so far, can spread out to rural areas as well. The main question will be, if the vehicles are to be used exclusively (diachronically) or together with other people at the same time (synchronically). It is also possible that future mobility offers include both variants within the same system, but with different pricing schemes. Nevertheless, in all use cases of sharing mobility the total number of vehicles can be reduced. With regard to the total vehicle mileage, movements of empty vehicles between the users can increase the number of driven kilometers. On the other side because of bundling the trips a reduction can be achieved in the case of synchronical (multiple people using the same vehicle) usage. This effect is dependent on the actual demand and the similarity of the mobility needs in terms of space and time.

Table 1. Overview of the shared mobility market, with and without automated vehicles (Haider et al. 2017)

Shared Mobility	*Shared Automated Mobility*	Sharing Type
Car renting Car sharing with fixed stations	Car Sharing or car rental with AVs	Diachronical usage of vehicles
Free floating car sharing Taxi	Car Sharing or Taxi without driver with AVs	
p2p car sharing Private taxi (e. g. Uber)	p2p car sharing with AVs	
Shared cab	Automated shared cab	Synchronical usage of vehicles
Ride splitting (e. g. UberPool)	Ride splitting with AVs (owner is no passenger)	
Ride sharing	Ride sharing with AVs (owner is passenger)	
Demand responsive transport	Demand responsive transport with AVs	
Conventional public transport	Conventional public transport with AVs	

3.2. Practice cases of sharing mobility

Since sharing systems are in use with conventional cars already today, and some aspects are the same for conventional and automated vehicles, we can study the implications of sharing vehicles to satisfy certain mobility needs. It can be expected – without the implementation of restrictive measures, such as laws – that sharing vehicles will not satisfy mobility needs for everyone. Personal possession of goods (such as vehicles) is a value in itself for a significant group of the population, and the perceived subjective feelings of independency when owning a vehicle in regard to satisfying mobility needs are strong barriers when promoting shared mobility.

3.2.1. ElektroMobil Eichgraben

On workdays Monday to Saturday from 7:30 until 22:30 hours, two battery-fuelled electric vehicles with volunteer drivers offer mobility services for members within the municipality of Eichgraben, Austria. The rides can be ordered via cell phone. The system is in regular operation since January 2016. Within the first year of operation, 70 different volunteers carried out 9300 trips including a car mileage of 54,000 kilometers. There are 200 members using the service as passengers. All members aged between 20 and 75 years and possessing a driving license are potential drivers as well. A driving school examines all new volunteer drivers before they are allowed to drive. The standard membership fee is 19 € per month with discounts for children and volunteer drivers. Peak hours in demand are between 16:30 and 19:00 hours, 95% of all 44 average daily trip requests can be handled within 20 minutes. Main user groups are elderly people and youths. The commuters' last mile to the train station is not provided; this would exceed the capacity of the volunteer-based system.

As interviews with users confirmed, the gained independency by asking other people for a lift is a strong argument for using the service, which means users are mainly without access to a private car. If possible in terms of spatial and day time distribution, trips are bundled by the drivers; there is no right for an exclusive (non-shared) lift in this service. The contribution to the community is the main motivation for volunteering, followed by the social contacts during trips and side events (there are regular meetings of the drivers in a pub in the village). The whole service relies on the strong commitment of the organizer (project champion) and the political support of the municipal assembly. The possibility of new social contacts within the municipality (social cohesion) is an important aspect of the success of the initiative. E.g. offering driving as a volunteer is a contact point for new residents. Enabled by the new mobility service, further social activities were initiated such as play-rounds, pub-rounds, and discussion clubs or similar events. Nevertheless the effects are limited for people with access to a private car (either as driver or as passenger). Only a second or third car in the household is being considered to be eliminated in a small number of households. Nevertheless there is some ecological effect because of the alternative propulsion systems, as some trips were shifted from private conventional car (e. g. children´s transport or trips to the railway station), especially, if trips are pooled. Since the social aspect of all participants are of great importance, the usage of an automated vehicle is seen as skeptical. Who is assisting elderly people exiting and boarding the vehicle remains unsolved as well as the age limit of children to use such a vehicle on their own. For both main user groups, the driver plays an important role. However, automated vehicles could attract new user groups, like commuters, which are right now excluded from the service in Eichgraben.

3.2.2. Cohousing Pomali Wölbling

The municipality of Wölbling in Austria is a rural area, conventional public transport is limited to 4 trips per day and the next train station is 5 km away. Most households are possessing more than one private car. In the year 2009 a cohousing project was founded in the municipality including 30 households (50 adults and 26 children). A third of these households do not possess a private car, although the majority of these inhabitants are commuting to other municipalities. A car sharing club was founded within the cohousing project, which has purchased 8 conventional cars used by its members with an average monthly mileage of 8,000 km. The project idea of this car sharing club was granted 10,000 € by the province of Lower Austria, which was matched by the members. With this amount of money the first (used) cars were purchased. The car sharing system is organized based on a paper calendar accessible in the community rooms of the residential house, where users simply filled in their needs for a car. The fee for using the car is kilometer based (0.25-0.35 € per kilometer), and there is no membership fee. With this money the running costs could be covered and further cars could be purchased. Two residents are responsible for organizational issues, for each car there is a specific person designated, responsible for organizing the maintenance and the technical checks. For this extra work up to 100 free bonus-km can be earned. For the accounting, all users need to fill in a log book for their trips. The users of this car sharing system are mainly infrequent trip makers rather than daily commuters. Main destinations are the public transport hubs in the area and visiting relatives and friends. Shopping trips are of minor importance as shopping is organized together by using a delivery service. Meanwhile a minibus was added to the fleet for common activities. As all members know each other already from developing the cohousing project, trust is a major success factor of the project. All members have easy access to the cars as the parking station is nearby the place of residence, which means there is/would be no difference in using a privately owned car. The high share of households without a car can be explained by the easy accessibility of the shared cars by avoiding the high purchase price of a privately owned car at the same time. Some residents' monthly usage costs exceed the costs of a privately owned car. Nevertheless, they prefer to use the car sharing system, as it provides more convenience (e. g. knowing someone else is taking care of the maintenance of the car). This proves the point, that cost efficiency is not the main driver in mobility decisions, but convenience is.

A disadvantage is seen, if a user drives the car to the next public transport stop, where the car is parked the whole day, not available for other potential users. Therefore in parallel a ride sharing initiative was launched. Another strategy to overcome this problem is the taxi service. If any other person is available, he/she is willing to bring or pick the person up from the public transport stop. For that reason, there is a pre-announced standby "taxi" driver available between 6:00-10:00 hours and 18:00-23:00 hours (last train). Again, free bonus kilometers can be earned by the standby "taxi" driver that way. As a consequence, not one household owns more than one car; there is a clear lower car ownership rate in comparison to other residents of the municipality. This has also consequences on the required parking space. The Co-Housing project has applied to lower the legal requirement of 2 parking lots per household to 1 parking lot, which is by far sufficient. The car mileage of the shared cars is significantly higher. Automated cars could solve the problem of parked cars far away from the residential premises, by making these cars accessible again. Younger and older residents could "drive" on their own, accompanied trips could be reduced. The project could then also be extended to other areas of the municipality, solving the car proximity issue. However, the residents of the cohousing with their communitarian approach are likely not representative for the overall population of the municipality, although the share of this group may increase based on such successful stories.

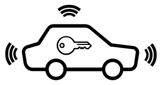
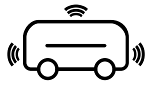
4. Scenarios for rural and suburban areas

Keeping in mind today's barriers of sharing system based mobility supply observed in practice examples (see chapter above), in a next step, scenarios were defined to analyse the full potential of sharing concepts within a specific Austrian municipality. As case study, the Austrian municipality of Perchtoldsdorf was chosen, as a high number of household travel survey data (3,178 total trips, 365 of which relevant for our case) are available for calculating the potential effects (BMVIT 2016). The municipality hosts 15,000 inhabitants and considering its location close to the capital city of Vienna, it can be seen as a typical suburban area.

For our impact analysis three different scenarios were taken into account and compared with the status quo (see table 2). The first scenario assumed that all existing private cars are substituted by automated vehicles without the implementation of any element of a sharing mobility. In the second scenario a shift of all individual motorized car trips recorded within the municipality towards a free floating car sharing application was assumed. Automated cars are used satisfying the municipal mobility needs without the need of a change of mobility behaviour among users. That means, a today's car driver can execute the desired trip (including all the passengers) without any waiting time. The automated car drives to the user as requested and after the trip the passenger exits the car and the automated car drives itself to the next user. Scenario 3 additionally pools trips with similar origin and destination and time. A „Dial-a-Ride-Problem" (DARP) algorithm was implemented to determine the number of cars needed and the mileage driven by the vehicles, as input for the comparison of the scenarios. As indicators for comparison, the car ownership rate, the car mileage and the mobility cost for the users were selected.

The evaluation of the aforementioned survey data was supplemented by research in four Austrian municipalities that already have small demand-responsive transport systems in place. Over the course of six months all trips were recorded using an app developed especially for this purpose. Over 40,000 trips were recorded and could be analyzed in order to find out how well the bundling of trips works in real world applications and how well demand-responsive transport systems perform already today.

Table 2. Scenarios for the use of automated vehicles that have been investigated.

 Private Use	 Car Sharing	 Plus Carpooling (Demand-Responsive Transport with Minibusses)
no sharing	sharing diachronically	sharing synchronically

5. Potential effects

5.1. Car ownership rate

Different effects can be expected with consequences on car ownership rate, if automated vehicles are in use. E. g. 13% of the population above an age of 10 years are affected by physical or mental restrictions to drive a vehicle (Sammer 2012). In the scenarios it is assumed that a share of 5% of the total population will indeed use this new option and will purchase an automated vehicle (scenario private usage of automated vehicles). The other part of the population may use existing cars in the household or need an accompanying person anyway.

For the car sharing scenarios, the distribution of the trips during day time of the Österreich-Unterwegs ("Austria on the move", BMVIT 2016) household travel survey were analysed (see figure 2). According to these data, a maximum of 11% of vehicles are in use at the same time in these areas.

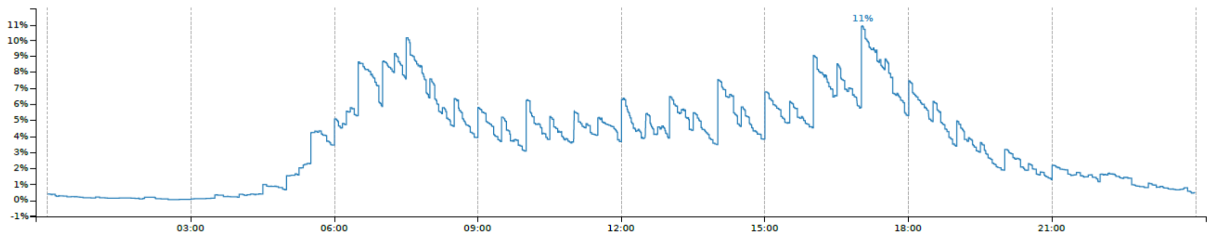


Fig. 2 Day time distribution of the share of cars used in relation of the total number of cars existing in central and peripheral regions of Austria (Haider et al. 2017)

In the scenario of a free floating car sharing, the travel time of the automated vehicle between the users needs to be considered as well. Assuming a maximum transfer time of 20 minutes increases the number of cars needed to satisfy the travel needs of the population up to 19%. Besides this analysis on macro level, for the case study of Perchtoldsdorf the same analysis was made based on simulation and it resulted in a value of 18% cars needed (considering the empty trips of the automated vehicles). Considering a share of cars not available because of maintenance a value of 20% was selected for the scenarios, which means 80% of the existing vehicles could be reduced in the extreme scenario. In the scenarios including carpooling the number of cars needed to satisfy the mobility needs depends on the service level, i.e. the accepted waiting time/shift of travel time (because of the intention to pool the trips) and the accepted time loss caused by detours to accommodate more trip requests. Table 3 shows some results of different simulations with different values. Whereas 5 minutes both for waiting and detour does not reduce the number of cars needed (comparing to scenarios 1 and 2 with 18%), half of the cars would have been needed (9%), if increasing this value to 20 minutes. In all scenarios, a shift from car trip to park and ride trip was not simulated here. However, such mode change has a potential to likely pool more trips or at least to reduce the travel time of the empty automated cars between the users. Table 4 shows the consequences on car ownership rate per scenario, if the full potential of sharing mobility is applied. This does not necessarily mean, the number of produced vehicle will decrease at the same amount, because the higher mileage caused by a more intensive usage will reduce the life span of the vehicles (see chapter car mileage and costs below).

Table 3. Dependency of waiting time and time loss because of detour and cars needed, simulation results (Haider et al. 2017)

Max. Waiting Time	Max. Time Loss Because of Detours	Share of Cars Needed (Compared To the Size of Today's Car Fleet)
5 min	5 min	18%
10 min	10 min	12%
20 min	20 min	9%

Table 4. Potential of changing Car ownership rate per scenario (Haider et al. 2017)

		Automated cars		
	Status quo	Private Use	Car Sharing	Plus Carpooling
Car ownership rate (cars/1000 inhabitants)	613	613	122	61
Increase/Decrease in fleet size		±0%	-80%	-90%

5.2. Car mileage

Car mileage is dependent on the person mileage because of desired destinations of the users on the one hand and the patronage of the vehicle on the other hand. If considering automated vehicles, the share of distance driven without users (in the scenarios mainly between the users) is relevant as well. Searching for a vacant parking slot could also be influencing the car mileage, if they are selected in greater distance of the destination, e. g. because of availability or cost, but this was not considered in the scenarios in this project (as mainly of importance in urban regions). As travelling is more comfortable and part of the time could be used for other activities, an increase of the person mileage is generally expected. In the scenarios with automated vehicles, the change of person mileage was assumed based on elasticities and changed generalised costs. Generalised costs constitute of time cost of users and operation cost of vehicles. An increase of the operation cost (because of the higher purchase cost of automated cars, on the long run ca. +3,000 € (Automobilwoche 2015), a reduction of the life span of the vehicle from 8 to 5 years and a decrease of the value of time for travelling with the vehicle can be expected. Concluding a cost reduction of the generalised cost by ca. 25.4% and a price elasticity of -0.5 (RVS 2010), an increase of 12.7% person travel mileage can be expected. Transferring the person mileage in car mileage caused per person, for the scenarios with car sharing an increase of the mileage with a factor 1.6 is assumed, covering the trips of the vehicle between the users as well. In the scenario with carpooling this increase will be substituted by the shared trips, which causes an overall reduction by a factor of 0.9. Summarizing the total mileage of the cars used, fewer cars (see chapter car ownership rate) are clearly used more often up to a factor of 10 (see table 5). The car mileage shows the low potential of saving car kilometres (or even an increase), although the trips are pooled, with its consequences on emission, if emission factors will not be improved at the same time.

Table 5. Potential of changing Person and Car mileage per scenario (Haider et al. 2017)

		Automated Cars		
	Status quo	Private Use	Car Sharing	Plus Carpooling
Person mileage (km/year)	8,920	10,050	10,050	10,050
Car mileage per person (km/person*year)	8,920	10,050	15,890	8,940
Car mileage (km/vehicle*year)	14,300	16,400	129,600	145,800
Increase/Decrease in total car mileage		+13%	+78%	±0%

Changes in car ownership rate and car mileage are key indicators when considering environmental consequences of changes in the mobility system. The drastic reduction in the size of the fleet made possible by the sharing of vehicles is not only promising in terms of saving emissions from the production but also because scarcity of resources is going to become more important in the future. Also, it's evident from our results that automatization should be combined with electrification of vehicles, otherwise there's a danger to make the situation even worse.

5.3. Mobility cost

In order to arrive at some first estimations a number of assumptions had to made. Number of vehicles per person and vehicle mileage per person and year have been taken from above. Automated vehicles were assumed to be more efficient, fuel consumption was therefore reduced by 10% in comparison to the status quo. For the shared use scenarios additional costs for maintenance and disposition of the fleet were taken into account. For the scenario with carpooling the use of vans was assumed which are considerably more expensive and consume more energy.

While personal use of automated vehicles would have a very similar cost structure compared to the status quo and would lead to a slight increase of +5% of yearly mobility cost, scenarios with shared use differ significantly (see table 6). Purchase cost becomes less important in comparison to energy cost and total cost can be reduced by more than 40% in both sharing scenarios. These are promising results, because they show that we can expect also economic benefits from scenarios that are to be desired from an ecological perspective.

Table 6. Potential of changing Mobility cost per scenario (Haider et al. 2017)

		Automated Cars		
	Status quo	Private Use	Car Sharing	Plus Carpooling
Purchase Cost (per person*year)	€ 2.256	€ 2.486	€ 497	€ 755
Energy Cost (per person*year)	€ 861	€ 873	€ 1.380	€ 1.207
Other Costs (per person*year)	€ 1.358	€ 1.358	€ 640	€ 637
Total Cost (per person*year)	€ 4.475	€ 4.717	€ 2.517	€ 2.598
Increase/Decrease in mobility cost		+5%	-44%	-42%

6. Conclusions

In order to set the path towards a sustainable mobility, automated vehicles should be implemented together with sharing components. Our research findings show that, compared with private use, sharing will likely reduce car mileage (when trips are pooled), reduce user costs and decrease the number of cars needed to satisfy the mobility needs of the people. But sharing requires some important elements, which can be learned from the sharing case studies analysed. A shared mobility system needs to cover all aspects of motorized mobility for its users, otherwise it will only be an additional option, which requires more resources at the end. It is necessary to consider the social aspect of the shared mobility projects as well. Trust in the system as well as towards other users is a crucial element for the (potential) users. Social interaction does not necessarily have to take place inside a vehicle only, but can be increased by facilitating mobility as a whole. Sharing responsibility for the organization and operation of these services is a social benefit for those involved. There is a lack of research about (self-organized) shared mobility to understand the obstacles and necessary preconditions for successful use cases. All the solutions analysed are capable to stimulate a positive impact on regional development. Our analysis showed that there is also a critical mass of users necessary to be able to operate these systems efficiently and with reasonable costs. Additionally, the relation between the user surplus and the critical mass is not linear. If such mobility supplies remain niche products, their impact on the mobility system (e. g. car ownership rate, car mileage or mobility cost) will be limited. A strong cooperation with conventional public transport as a backbone of the system could strengthen the offering of the shared mobility concepts, which is serving the first and last mile, and is capable to initiate a significant mode shift and a reduction of car ownership. A combination with delivery services could further increase the efficiency and financial sustainability of automated vehicle supply in the region. As an overall conclusion, we suggest that if technological innovations in regard to automated driving are to uncover their full potential, they need social innovations along the lines: capacity building within communities, creation of the legal framework, organizational and economic settings, but also the development of the right products and services.

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