The Unintended Social Consequences of Driverless Mobility Services – How will Taxi Drivers and their Customers Be Affected?

Christina Pakusch, Paul Bossauer, Gunnar Stevens

Information Systems, University of Siegen, Siegen, Germany, {christina.pakusch; paul.bossauer; gunnar.stevens}@uni-siegen.de

Abstract. Social sustainability effects of autonomous vehicles are being discussed in a controversial manner. While there are numerous social benefits to be expected with the advent of autonomous vehicles, some people will face drawbacks of this development. On the one hand for those who earn their living by driving and on the other hand for those customers who are reliant on human assistance to conduct a taxi ride. In order to better anticipate the size of this group and thus how great the threat to the taxi driver's profession is to be replaced, we analyze secondary data on taxi use in Germany. The results show that the proportion of mobility-impaired passengers is 9%, accounting for about 18% of all taxi trips, indicating that there is a small but significant number of customers whose needs probably cannot be met by autonomous vehicles, and who will potentially continue to rely on human assistance in the future.

Keywords: Social Sustainability, Taxi, Shared Autonomous Vehicles, Jobs, Mobility Impaired

1 Introduction

Fully automated vehicles have the potential to revolutionize our mobility in a way that is hard to predict [35]. Given that autonomous driving will make vehicle sharing easier and more comfortable, experts hope for a greater shift away from the private car to usage-based mobility services [13,33]. Such shared autonomous vehicles (SAVs) are being controversially discussed with regard to their potential contribution towards a more sustainable mobility.

In the context of Fridays for Future and the omnipresent discussions about climate change, the ecological dimension of sustainability is currently moving into the foreground. This is also reflected in the exploration of possible consequences of autonomous driving. Here, the focus is on the effects on traffic, especially the potential for congestion avoidance and efficiency gains through connected driving and platooning, as well as possible rebound effects and, depending on this, the influence on transport-related emissions [3,16].

The possible social effects of autonomous driving, on the other hand, are discussed to a lesser extent. Experts agree that here, too, major impacts are to be expected both on the individual level and on a societal level. Potential benefits include increased safety for road users, a significant reduction in traffic-related emissions and noise, and improved mobility and autonomy for those who are restricted in their mobility [5,22].

However, the development of unmanned SAVs poses serious threats to two groups of people that shall be considered in this article: firstly, to professional taxi drivers, whose job threatens to become obsolete with the introduction of SAVs, and secondly, to taxi customers with impaired mobility, who are dependent on mobility offers for which a certain level of human support is guaranteed that might get lost with the automation of the taxi service . The SAV concepts envisaged so far hardly take the needs of both groups of people into account. The reason for this is understandable: the average taxi user is rather young and autonomous [18], i.e. not dependent on help. Therefore, it makes sense to design SAV concepts in such a way that most users can make use of them. However, it is not known what relevance the group of potentially support-needy users actually has. Irrespective of a social-ethical necessity to consider these people in need of support in the conception of new mobility services with self-driving cars, this group could also

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represent an interesting target group for business reasons, depending on its actual size. Quantifying the group of potential taxi users in need of support thus reveals, on the one hand, the potential for assisting taxi drivers, who might also have a right to exist in times of autonomous vehicles, and on the other hand, the potential for the design of SAV concepts focusing on mobility impaired people. With this in mind, we address the following questions in this paper:

1. What share of the taxi business is accounted for by taxi rides with mobility-impaired customers?
2. How can the needs of mobility-impaired people in times of autonomous driving be considered?

Since there is a lack of reliable figures on the importance of this vulnerable group regarding its taxi use, we evaluate a survey on taxi use conducted in Germany in 2014 [18] with regard to these two questions. Before discussing the results and their implications, the following chapter provides some theoretical and contextualizing information on the automation of the taxi service and the potential social impacts.

2 Automating the Taxi Service

2.1 Automation of the Taxi Industry

Taxis are nowadays an important part of the public transport system, in particular for addressing opportunity-based mobility [17]. In Germany, taxis are part of the public service, which is under the care of the public authorities. There are more than 28,000 taxi and hired car companies with more than 53,000 vehicles, transporting more than 400 million passengers every year. In 2018, the estimated revenues are around 5.3 billion euros [7]. Most taxi rides were for private reasons (83%), only 17% for professional reasons. More than half of the journeys (53%) are made in connection with events. Taxis are used particularly in metropolitan regions. The passengers are younger than average (up to 29 years) and are above average educated [19]. With the taxi driver as a human person being part of the mobility service, he or she provides certain assistance and support. For example, taxi drivers not only help their passengers with loading and unloading luggage, wheelchairs, walking aids or shopping, but if necessary also pick up customers in need of help in their homes, help them down the stairs, get into the vehicle and fasten their seat belts [32].

There is no doubt that autonomous driving will have a disruptive effect on the taxi industry. The Society of Automotive Engineers defined five stages of vehicle automation, ranging from level 1 (assisted driving) to level 5 (fully automated driving) [43]. According to that taxonomy, vehicles in levels 4 (high driving automation) and 5 (full driving automation) can be operated without human intervention. With level 5 vehicles, taxi services could be fully automated and run unmanned. Considering that the driver accounts for a significant part of the costs for taxi operators [14,22], their elimination seems to be the logical consequence. Of course, the absence of a human driver would change the taxi service in its nature. Then, SAVs could present a flexible and dynamic door-to-door service [26]: the passenger selects the desired vehicle by application and requests a starting location. The vehicle picks up the user at his or her desired location. If several passengers share the same vehicle, the system calculates the optimal route combination automatically [21]. Due to the high level of comfort and flexibility combined with relatively low travel costs, the common use of automated vehicles could become the dominant concept of individual mobility [13]. Thus, SAVs are expected to provide the travel experience of private vehicles including door-to-door service, but at low cost, without the burden of financial investment and ownership of private vehicles.

According to a recent forecast, self-driving cars may become available in many urban areas during the 2020s and 2030s [22]. Overall, the most crucial driving forces are the technology itself (and the speed of its improvements) and the policies depending on how restrictive or supportive they act [27]. Given these advantages of SAVs and the relatively long lifecycles of private cars, experts believe SAVs present a concept that will help autonomous driving to

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make a breakthrough [30]. Given that SAVs can be offered at relatively low cost, some think it is likely that traditional taxis will be the first transportation mode to be replaced by SAVs in urban areas [13,45].

2.2 Social Impacts of Autonomous Vehicles

Regarding social effects, autonomous driving will increase social sustainability in manifold ways. The greatest expected benefit is improved traffic safety. In Germany about 3,000 people get killed in traffic accidents every year, more than 65,000 get seriously injured. With 88.4%, most of these accidents are caused by human error [46]. According to the German Federal Statistical Office, maneuvering errors, disregard for right of way, distance errors, inappropriate speed, and alcohol abuse are the most common causes of accidents [46]. As fully autonomous vehicles take over the driving task completely, they hold the potential to reduce the amount of accidents drastically by avoiding human errors [22].

People would no longer have to focus on driving but could use their time otherwise [22,47]. Further, autonomous driving offers the opportunity to make traffic flow more efficient. Connected driving can prevent, reduce or avoid stop-and-go traffic and congestion [13,33]. In particular, the so-called platooning can be used to optimize traffic flow, since vehicles can exchange data with each other and coordinate driving speed, braking characteristics and distances between the vehicles. As a consequence, vehicle emissions could be reduced by up to 94% [15]. The resulting reduction in air pollution and noise will have a positive effect on people's health [40].

Autonomous mobility on demand can increase mobility in rural areas that are not or only insufficiently served by regular public transport and thus contribute to equal mobility [31]. Furthermore, the supply of goods and services can be improved through autonomous driving by reducing transport times and increasing the frequency of service intervals. This is also particularly important in rural regions, where the municipal supply of medical care or shopping facilities is often limited.

Furthermore, autonomous driving is expected to increase social sustainability, as it allows for a socially more equitable and self-determined access to and use of mobility [5]. Persons whose ability to drive is temporarily or permanently restricted or not given at all achieve a higher degree of individual mobility. Autonomous driving is thus a great opportunity for people who are too young to drive, for people with disabilities and for the elderly. With the ageing population in industrialized countries, autonomous driving can play an important role in providing access to mobility for elderly people who are losing their ability to drive [25].

So, while autonomous driving offers great potential in terms of social sustainability, there are also some downsides to be expected. These include concerns about data protection and privacy of road users as well as concerns about technology dependence and human immaturity as mobility providers learn much more information about their customers' everyday mobility and know exactly where they live, work and shop [9]. Another much-discussed drawback is the negative impact the introduction of autonomous vehicles could have on the labor market. Some experts argue that there will be no need for professional drivers in the age of autonomous driving [10,22,50]. These include bus drivers, truck drivers, taxi drivers and chauffeurs, sales workers, ambulance drivers. Looking at the large number of people who make a living from those rather low-skilled, undifferentiated jobs, the threat which automation might cause becomes evident.

The way the SAV service is envisioned today, SAVs present an evolutionary development of existing car-oriented mobility services (such as taxi services, ridesharing services, rental cars, and carsharing) towards their full automation [36]. Walker and Marchau (2017) among others believe that as a consequence there will be no more employment for taxi drivers [8,50]. However, these researchers and other experts remain quite undifferentiated and vague in making such statements regarding the role of taxi driving in the age of self-driving cars. Others, such as members of the taxi industry are certain that the profession of the taxi driver will rather redefine itself, not disappear [29]. Independent of

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how exactly the transformation will look like, given that in Germany 255,000 people work as a taxi driver [7], this would mean a large impact on the taxi industry.

Recent studies on the acceptance of autonomous driving and SAVs have indeed confirmed the expert opinion that users have a positive attitude towards the use of such mobility concepts [21,37,48]. If unmanned, fully autonomous taxis were cheaper than manned taxis – as suggested by many simulation studies [12,13] – users would prefer the driverless taxi to the manned taxi [34,38]. In this respect, these empirical studies confirm the potential risk that human taxi drivers face with further automation of vehicles. However, a recent qualitative study by Pakusch et al. (2020) with professional taxi drivers showed that they see a right to exist even with the introduction of SAVs [32]. Some of them described their clientele as one that is characterized by regular customers who regularly require assistance from the taxi drivers that goes beyond the normal level of just bringing the customer from A to B. The authors concluded that the nature of the interaction between human driver and passenger is crucial in determining whether a human person is required to be present in self-driving taxis to assist these passengers in using the taxi.

Currently, there are indeed many levels of interaction between taxi driver and passenger. On the one hand, there are interactions of a communicative nature. This includes communication with regard to the processing of the transport order, such as the communication of the destination or other customer needs, or conversations about payment. It also includes the conversations that taxi drivers have with their customers, which range from small talk to information about the region, the city, or regional institutions to confidential or comforting conversations. Taxi drivers also help with loading and unloading luggage, as well as with stowing other items such as wheelchairs or walkers. The taxi drivers go beyond that kind of service whenever they transport passengers in need of special assistance, such as those who are physically impaired or are otherwise restricted in their mobility, when boarding and exiting the vehicle and when fastening their seat belts. They also pick them up at the apartment door, carry their luggage or shopping and physically support them when walking [32]. Regarding this latter group, the human taxi drivers represents a central figure that enables this clientele to be mobile. If, as a result of the automation of the taxi, the aforementioned ways of interacting with a human driver will no longer be possible, some mobility impaired people will be restricted accordingly.

2.3 Designing for Passenger-SAV-Interaction

In design-oriented SAV studies, however, this group has so far received little attention. Their relevance with regard to the job of taxi drivers has accordingly been little discussed. Kim et al. (2019) analyzed the process of taxi use in order to identify relevant interaction issues that need to be considered in order to replace the human taxi driver. By drafting a customer journey, they map an average taxi ride of a passenger whose only need is to be transported from A to B [20]. While they do identify relevant interaction issues such as "Confirming the destination and route" or "Confirming the exact drop-off location", their study focuses on the average – thus rather young and fit – users. Other studies focus on the user experience design of (shared) autonomous vehicles with different focuses: special attention is given to interior design, user interface design, and vehicle pedestrian design [41,42,47]. Bass (2018), using a method triangulation, concludes in his study that user experience design should address user concerns regarding travel time, comfort, and personal safety [4]. Having participants draw their own designs of SAVs, Stevens et al. consider time use as a starting point for interior design [47]. Pfleging et al. (2016) among others make design proposals depending on the activities that users can imagine doing in AVs and conclude that highly automated cars need to provide a broad range of applications to support these activities [41].

The vast majority of those studies, thus, has in common, that the needs of mobility impaired people and the interaction of drivers with these people are not being investigated [49]. However, some point out the importance of taking into account the needs of these particular groups of people when designing SAVs, not least because people with

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disabilities often feel isolated and disadvantaged. Access to mobility is an important aspect of participating in social life and has an impact on the quality of people‘s lives [44].

Taking up this problem, there are a few studies that focus on people with reduced mobility. The focus group study of Brinkley et al. (2017) revealed that people with visual impairments consider self-driving vehicles to have a great potential increasing their mobility and independence, but they fear that their specific needs will not be taken into account in the development and design of the respective automated mobility concepts [6]. The comprehensive study by Allu et al. (2017) analyzed the needs and requirements that people with different types of disabilities have concerning AVs and makes suggestions for user interfaces adapted to the respective type of disability to facilitate the exchange of information [1]. Lutin (2018) demands that the needs of people with mobility impairments must be taken into account when designing autonomous vehicles. Among other things, he recommends the use of robotic assistance to facilitate getting in and out of the vehicle and to secure the people's equipment on board [23]. Other services that go beyond these and partly take place outside the vehicle, but are nevertheless part of today's taxi service, are not covered by these studies either. However, these represent a need for which a human assistant may still be needed in the future.

3 Approximating the Relevance of Needy Customers in the Taxi Industry

3.1 Method

Data on the use of taxi services and taxi customers in Germany are rare. For the analysis of the usage data, we use an existing data set, which was collected and published in 2014 [18]. The representative survey on customer satisfaction with taxi companies was commissioned by the German Taxi and Rental Car Association (BZP). The basic population consists of German-speaking persons from the age of 18 who live in Germany and have a telephone connection. The data was collected through Computer Assisted Telephone Interviews (CATI). The sample was randomly selected using the ADM telephone sampling system. Within each household, the target person was selected randomly using the last-birthday method. The net case number is n=1,580, of which 488 were interviews with taxi users and 1,092 were interviews with non-users. The interviews were conducted over a period of 2 weeks from 13 January to 27 January 2014.

The results of the survey have been published in a general report and a tabular report and are not available as raw data but only in aggregated form. The data allow a descriptive analysis. In the analysis we focus on those taxi users who stated in the survey that their mobility is limited due to health problems. We analyze how large this group is and how they differ from the other taxi users in terms of their taxi use. Since the data was partly available in aggregated form (example: when asked how often the participants used a taxi in the last 6 months, the answers were partly clustered in groups: 6-10 times), we calculated conservatively – i.e. with the lower values in each case.

3.2 Findings

First of all, the survey showed that about one third of the people occasionally use a taxi (488 of the 1580 respondents). Of these 488 people, 72% used it relatively rarely, only one to three times during the relevant period, a further 18% used it occasionally, i.e. between 4 and 10 times during the half-year period, and 9.4% used the taxi intensively, i.e. more than 11 times. Of the active taxi users, 9.2% (45/488) are restricted in their mobility due to health problems, such as walking difficulties, impaired vision or other restrictions. They form the group that is potentially in need of assistance and dependent on a taxi service. They differ from taxi users who are not restricted in their mobility both in terms of their demographic characteristics and their taxi use behavior. Compared to the non-restricted taxi users, they are characterized by a higher age: While only 22.5% of the non-restricted taxi users are 60 years old or older, the proportion is almost 70% among the mobility impaired. They are more likely to live alone in the household (35.6%) than the non-

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Table 1: Taxi Use of Mobility Impaired Individuals I
(Extract from [30], translated)

		Total	Mobility-Impaired			
			Yes		No	
		488	45		444	
Frequency of use	Intensive users	47	10	22%	36	78%
	Occasional users	90	11	13%	79	87%
	Rare user	341	23	7%	328	93%
Last taxi ride alone or together with other people	alone	150	22	48%	129	29%
	1	120	12	27%	109	24%
	2	74	3	6%	71	16%
	3	74	7	16%	67	15%
	4	39	2	4%	37	8%
	> 5	32	-	-	32	7%
Taxi order	By telephone	359	39	88%	320	72%
	Per app / Internet	2	-	-	2	*
	Taxi stand	70	2	6%	68	15%
	Hailing on street	49	2	4%	47	11%
	Other	4	1	1%	4	1%
	Don' t know	4	*	1%	4	1%
Age	18 to 29	134	5	11%	129	29%
	30 to 39	70	1	1%	70	16%
	40 to 49	80	1	2%	79	18%
	50 to 59	74	7	16%	67	15%
	60 to 69	56	9	21%	47	11%
Number of persons in household	1	74	16	36%	58	13%
	2	178	22	49%	156	35%
	3	77	6	14%	71	16%
	4	91	1	2%	90	20%
	> 5	69	-	-	69	16%
Occupation	Fully employed	250	5	11%	245	55%
	Employed part-time	54	3	7%	51	12%
	Unemployed	6	-	-	6	1%
	In training	50	1	1%	49	11%
	Housewife/househusband	16	3	7%	13	3%
	Pensioner	111	33	73%	78	18%

restricted (13.1%) and are less likely to have a car in the household (62.2% compared to 87.8%). At 73.3%, most of them are pensioners (Table 1).

Compared to other taxi users, mobility-impaired individuals use a taxi service much more often. About 22.7% of them are intensive users, i.e. they use taxis comparatively often, some even several times a week (8.9%), another 25% use them regularly, and about 52.3% rarely use taxis. Among the other taxi users, only 8.1% are intensive users, 17.3% are occasional users, while about three quarters use the taxi only rarely. This illustrates the high relevance of taxis for people with limited mobility.

If we look at all taxi users, it is clear that by far the largest proportion (59%) of journeys were made in connection with events, parties or other leisure activities (Table 2). Here, however, the non-restricted individuals are particularly predominant. For them the proportion is as high as 63.6%, while only 10% of the mobility impaired use the taxi for

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Table 2: Taxi Use of Mobility Impaired Individuals II
(Extract from [30], translated)

	Total	Mobility-Impaired			
		Yes		No	
	438	41		397	
Events, parties or other leisure activities	259	4	*11%*	252	*64%*
Arrival / departure to airport / train or bus station	49	3	*8%*	45	*11%*
Private vehicle not available	17	3	*6%*	15	*4%*
Public transport not (no longer) available	11	-	-	11	*3%*
Medical / health reasons / patient trip	50	21	*52%*	29	*7%*
Visiting relatives, friends	29	3	*8%*	26	*7%*
Shopping / procurements / transport of goods or items	9	3	*8%*	6	*1%*
Acute / sudden situations	6	-	-	6	*2%*
Other	9	3	*6%*	6	*2%*

these reasons. In contrast, they use the taxi mainly for health or medical reasons or use it for official patient trips (52.5%) and they also use it more frequently for everyday trips such as shopping or other services.
Nearly every second taxi user with limited mobility uses the taxi on his/her own (48%). This is much less common among users without mobility restrictions (29%). Many of these potentially needy passengers are therefore left on their own during taxi rides and do not receive any assistance from an accompanying person. For those, the presence of the human driver is therefore potentially most significant.

Overall, the survey showed that taxi customers were very satisfied with the taxi service. For the mobility impaired more than for the rest of the population, the positive experience is more due to the punctuality, reliability and helpfulness of the taxi drivers. Overall, people with reduced mobility rated the price-performance ratio of a taxi better (1.9) than people without reduced mobility (2.3). This could be due to the fact that they rely to a certain extent on the taxi and benefit not only from the pure transport but also from other services, such as the helpfulness of the drivers.

With regard to the way in which the taxi is ordered, it is noticeable that passengers with reduced mobility almost always order the taxi by telephone or from the taxi dispatcher (88.6%), while others more often call the taxi spontaneously by going directly to a taxi stand (15.3%) or by hailing a taxi at the side of the road (10.6%). People with limited mobility therefore tend to plan their taxi journey in advance. However, it cannot be ruled out that this effect is alternatively attributable to the higher age.

In total, the respondents used taxi services for 2315 trips during the 6-month period. On the assumption that the journeys of persons with reduced mobility will be relevant in terms of human assistance for taxi rides, it is useful to find out what proportion of the total number of journeys is made by persons with reduced mobility. For this purpose, we analyze how often the mobility-impaired users have used a taxi during the 6-month period. The figures vary between 10 people who used a taxi only once and 7 people who used a taxi more than 15 times. According to a conservative calculation, passengers with restricted mobility account for at least 419 of the 2315 trips. This corresponds to a share of at least 18.1%. Thus, although the mobility-impaired account for only 9.2% of the users, they account for 18.1% of the total number of trips due to the more intensive use of taxis.

4 Discussion and Implications

The results suggest that in the age of SAVs there will be mobility consumers who will need human assistance – i.e. some kind of a travel companion – to use autonomous vehicles. These findings are of particular importance for two

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groups of people that are in the focus of this paper: On the one hand for taxi drivers, whose professional right to exist in an autonomous future depends on whether their human person is needed or offers passengers added value. On the other hand, for the mobility impaired themselves, whose special needs should be taken into account when designing driverless taxis. Both aspects will be discussed in more detail below.

4.1 Relevance and Implications for the Taxi Business

A share of 18.1% of the total number of journeys does not constitute a majority, but nevertheless represents a significant quantity for the taxi business. Of course, the share of 18.1% does not automatically mean that even in the age of autonomous vehicles, 18.1% of the trips will be characterized by the fact that these passengers need the kind of support that makes a human person indispensable. Rather, this estimation should be understood as the best possible approximation that is possible on the basis of the data available today.

Some aspects must be taken into account when interpreting this estimation. Firstly, there are reasons why the proportion of journeys where human assistance is required is lower. Not all mobility-impaired individuals per se require assistance when using a taxi. While there are some passengers with reduced mobility who cannot make it to the vehicle alone, cannot get in on their own, cannot stow their luggage on their own and cannot fasten their seatbelts, there are certainly some passengers whose limitations are not so extensive. These passengers could possibly use an SAV, as it is currently being designed for standard journeys [20] or for special activities in the vehicle [42,47], even without human assistance. With regard to the economic importance of these journeys, it must also be added that this figure is the absolute number of journeys – the data do not provide any information on how long the journeys of those individuals with mobility impairments are compared to the average journey, i.e. what proportion of the turnover of the taxi business these journeys represent.

On the other hand, it is known that the demographic structure in western countries like Germany will change in the future. Given the perspective that in these countries people are getting older and therefore more diseases are to be expected [39], it is possible that the number of people who need help with their mobility will increase.

With regard to the taxi business and the importance of human taxi drivers, these figures confirm the statements made by taxi drivers in a recent qualitative study that pointed to the relevance of customers in need of assistance [32]. For example, some professional taxi drivers stated that they not only have a clientele that sometimes requires intensive physical assistance when using the taxi service, but that for some drivers this type of customer forms a significant part of their regular clientele. The calculated figures therefore support the argumentation of these taxi drivers that in the age of autonomous taxis they will not be completely dispensable due to these required supporting services. However, it is questionable whether professional taxi drivers will actually continue to perform this type of task. At present, the supporting services are closely linked to the driving task and in combination form the taxi service. However, it is questionable whether it will actually still be the taxi drivers who will take on the role of a driving companion in a future in which the driving task has been separated from the supporting service. Whether taxi drivers would even like it if their tasks were to concentrate solely on the supporting service is another question. Ultimately, the role of the assisting person could be taken over by different persons, who in turn are commissioned either by the SAV operators or private companies, public institutions or the mobility-impaired people themselves. SAV operators could retrain taxi drivers or train new staff to be used for such journeys requiring assistance, similar to the program Uber and Lyft recently started in some countries (UberAssist, [11]). In addition, nurses for the elderly or nurses for the sick could take over these tasks. It is also conceivable that in future more volunteers will take care of the needs of people in need, for example in the form of a social-oriented gap year or voluntary work, as is common i.e. in Australia [40]. Finally, it is also possible that the support has to be organized by the needy individuals themselves, by assigning assistants or by asking people close to them for support.

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We know from examples such as the elevator operator that occupations can remain in a modified form even though they are basically no longer needed. Its primary task of opening and closing elevator doors and directing the elevator to the desired floor has been rendered obsolete by the invention of button operation. As a result, elevator operators have disappeared in most industrialized countries, as elevator passengers could now select the floor themselves and the elevator doors closed and opened automatically. Nowadays, elevator operators are therefore only found where monitoring of elevator operation is necessary for safety reasons. In Europe, they are rarely found in hotels or large department stores, while the so-called elevator girls are still widely found in Japan [28]. A similar development is conceivable in the taxi industry: Some providers could employ taxi drivers or driving attendants in their vehicles in the sense of an exclusive service, regardless of passenger restrictions.

4.2 Relevance and Implications for the Traditional Taxi User

In the scenario where the mobility impaired individuals will continue to rely on the traditional taxi service, while others will switch to unmanned SAVs, the density of human assisted taxis will decrease. As a result, manned taxis are expected to have longer journeys to the customer's pick-up location on average, with more empty time and therefore higher costs.

This results in new, unsolved challenges i.e. as to how a nationwide supply of traditional taxis can be ensured, how the increased costs can be passed on to the individual and the community, and how at the same time fair working conditions for taxi drivers can be ensured.

As mentioned, in Germany taxis are part of the public service, which is under the care of the public authorities. In this case, business models are conceivable in which traditional taxi services with human assistants are subsidized by the state. For example, it would be conceivable that taxi drivers would receive a kind of basic salary for providing the taxi service, regardless of whether it is requested by customers. The exact form of a "stand-by fee" would certainly depend on many factors, such as the level of population density (urban/rural), when and how many hours the taxi service is provided, etc.

4.3 Considering the Impaired in the Conceptual Design of Shared Autonomous Vehicles

In the development and design of mobility concepts with self-driving vehicles, the focus is currently on the average person or average taxi customer. Experts and scientists generally agree that fully autonomous vehicles have a great potential to help non-drivers, the young and the elderly, as well as people with disabilities to achieve better mobility and greater independence, and thus to create a more equal access to mobility [24]. However, especially the groups of people with different kinds of disabilities currently receive little attention in the design of autonomous vehicles in general and automated taxis in particular. Our results have shown that the number of those who potentially need human assistance in the use of SAVs is considerable.

Some design approaches already take special groups of people and needs into account. In their comprehensive study, Allu et al. (2017), for example, have worked out what kind of interfaces for communication are suitable for people with different kinds of limitations [1]. Amanatidis et al. (2018) also study user interfaces and formulate different design recommendations to equally meet the needs of all users including the impaired [2]. User interfaces should be able to adapt to the abilities of the individual user. For example, interfaces for people with a visual impairment should be controllable via voice control. In addition, the displays should be adaptable in terms of brightness, contrast, angle and font size, and the user should be able to first, individually enlarge and reduce the size of the contents on the display, and to second, hold the user interface in his hand to adjust the viewing distance individually. Voice control would be equally interesting for people with reduced mobility, as they may not be able to move as freely within the vehicle as unrestricted persons. In addition, the vehicles should offer the possibility of easy access and egress, e.g. in the form of

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ramps that allow wheelchairs or other walking aids to enter or leave the vehicle. Accordingly, there must be enough space inside the vehicle, or space must be able to be created (e.g. by folding away seats), where a wheelchair can be placed and securely fastened or where other supporting objects can be placed and secured. For those passengers who have very severe physical limitations, there must also be the possibility of automatic seat belt closure. Similar to a roller coaster, these should be able to automatically fasten a seat belt or safety bar and should also be controllable by voice commands. Eye tracking and gesture control are also desirable features for the severely restricted passengers [1,2].

However, such studies and the resulting design approaches usually consider the SAV as a closed entity, i.e. the interior, the interfaces, and the access of the vehicle. Since some passengers require assistance before entering or leaving the vehicle, it is necessary to extend the design of SAVs to additional services and support. Thus, when designing the SAV concept, assisting persons should also be considered to take over such supporting tasks as discussed in the latter section.

Irrespective of the fact that our study has shown that a relevant proportion of all taxi rides are carried out by such people with impairments, there is also a social and moral obligation for scientists, developers and designers to take into account the special needs and requirements of these people. If, on the other hand, this vulnerable group is disregarded, this would result in an increasing isolation and a further deterioration of their already limited mobility, independence and autonomy.

5 Limitations

This work does not come without limitations, of course. First of all, the accuracy of the results should be mentioned here. The method of secondary analysis uses existing data, data that were originally collected for a different purpose than the present analysis. In this case, the authors did not have access to the raw data of the primary study, so that they only evaluated the existing partially aggregated values with regard to the present research questions. More detailed and precise data on the dependence of taxi users on human assistance are needed in order to make reliable statements.

Furthermore, the results and implications only have limited validity for other countries in which the use of taxis, especially the servicing of people with restrictions, differs from the conditions in Germany. For Germany, however, the sample is representative, so the findings are at least to some extent transferable to other western countries with a similar age structure.

With regard to the significance of the calculated figures, it must also be critically noted that it remains uncertain what proportion of people with mobility impairments will actually need assistance in using a taxi or, in the future, an SAV.

6 Conclusion

Autonomous driving is on the threshold of becoming reality. Different mobility concepts are being developed and some of them are already being tested within the framework of projects. Experts expect that automated taxis in particular – also often referred to as shared autonomous vehicles – could help autonomous driving to gain social acceptance and widespread adoption [30]. While for some people this development may mean easier and more equal access to flexible mobility, for others it poses a threat. On the one hand, for the group of taxi drivers whose job could become obsolete with the introduction of autonomous, unmanned taxis, and on the other hand, for people with impaired mobility who are dependent on human assistance when using mobility services.

While these dangers are generally known and are being debated in the literature, there is a lack of precise knowledge about how large the group of these mobility-impaired people is and what proportion of their trips make up the taxi

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business. By means of a secondary analysis of a representative customer survey on taxi use from 2014, we calculated that 9.2% of all taxi users in Germany are restricted in their mobility and that these customers are using taxi services more often than the average person [18]. In total, they account for approximately 18.1% of all taxi trips. This relatively high figure shows how important the offer of taxis is for the mobility of these people. At present, people with reduced mobility are only considered to a small extent when designing autonomous taxi services and usually the consideration of their needs is limited to the interior design [1] or the design of user interfaces [6] of autonomous vehicles. However, there remains the danger that consideration of this type of restrictions is not sufficient if, for example, assistance is also required outside the vehicle – such as accompanying passengers from the front door to the vehicle - to use the taxi service. In this respect, it is necessary to check whether SAV services, as they are currently being designed, actually address the needs of all people, or whether there are users who experience a disadvantage due to the absence of a human person in the taxi service.

Whether human taxi drivers will still be needed in a future with autonomous taxis cannot be conclusively assessed. The calculation shows that the proportion of taxi customers whose mobility is restricted is relatively high. Some of the tasks that taxi drivers perform today will probably also be in demand in a future with autonomous taxis. While the driving task will be eliminated, taxi drivers could concentrate on these support-oriented tasks. However, it is also possible that these tasks will be taken over by other people.

While the presented figures should be viewed with caution, they do provide an important indication of how relevant the group of people with mobility impairments is to the taxi industry, and how important it is not only to consider their special needs when designing mobility services with autonomous vehicles, but also to let them participate directly. A further study could therefore investigate this group of people with restricted mobility more closely and ask them whether they can do without human assistance, for what reasons they could not do so, and how an autonomous taxi would have to be designed so that they could use it without human assistance.

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