Exploring the Impact of Autonomous Taxis on People with Disabilities

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Abstract—**Over the past two decades, transportation has become more accessible, but people with disabilities still face significant barriers to accessing these services. This research focuses on the impact of autonomous taxis on people with disabilities, an area that has seen limited improvement. The study aims to answer two research questions: 1) How do traditional taxi experiences shape expectations of autonomous taxis in terms of disability accessibility? 2) To what extent does the autonomy of self-driving taxis contribute to a perceived increase in travel freedom? Thirty-two semi-structured interviews were conducted with administrative staff from disability organizations, and the perspectives of 39,079 organization members were included. Thematic and sentiment analyses were applied to analyse the findings, which revealed three main themes: onboarding, in-vehicle conditions, and offboarding. The absence of a driver was strongly correlated with a positive sentiment of increased travel freedom, indicating that autonomous taxis could provide enhanced accessibility without the limitations or biases associated with traditional taxis. Participants expressed concerns about driver attitudes and behaviour as negative experiences with traditional taxis. In contrast, with autonomous taxis, their main concern was the availability of human assistance to meet specific user needs throughout the journey. This study emphasizes the necessity for further research into the diverse and intricate spectrum of disabilities, as well as the importance of user-centric market research in the design process. Such research is crucial in achieving the overarching goal of improved accessibility.**

I. INTRODUCTION

The transportation sector is witnessing significant advancements in technology, promising several benefits for the environment, economy, and society, including reduced congestion and crashes, lowered carbon emissions, and increased accessibility. However, realising the full potential of these advancements requires a focus on human-centric impacts and the design of initiatives accordingly. In the United Kingdom, transport companies are experiencing a monthly loss of £42 million due to the absence of inclusive services [1]. This paper explores the potential of autonomous taxis to improve inclusive mobility for people with disabilities in the United Kingdom. The study identifies the current challenges and barriers faced by people with disabilities in accessing taxi services and proposes design and regulatory solutions to enhance their freedom of mobility. According to the definition of disability under the Equality Act 2010, a person is disabled if they have a physical or mental impairment that has a substantial and long-term negative

effect on their ability to do normal daily activities [2]. They encounter several mobility challenges, and autonomous vehicles (AVs) are one solution that is being considered to increase access for all. Shared AVs such as taxis are anticipated to be vital in increasing access to commuting as much as private self-driving cars [3] [4]. This is already being seen in several countries, with self-driving taxis being operated in Dubai, United Arab Emirates [5] and Cruise operating in California, USA [6]. Although these services are on a small scale, it suggests autonomous taxis are close to being deployed more widely.

Currently, people with disabilities experience difficulties accessing taxis and private hire vehicles (PHVs) due to a lack of accessibility features, such as wheelchair ramps or induction loops for people who have hearing impairments, as well as driver behaviour [7]. In 2021, 67% of UK authorities mandated the inclusion of wheelchair-accessible taxis, which is a slight increase from the 65% reported in 2019. Conversely, only 4% of authorities required the same accessibility for PHVs [8].

Therefore, this study emphasizes the importance of considering elements that need attention and including the voices of this specific target group to achieve maximum societal and economic benefits for new technological advancements such as autonomous taxis. One of the essential needs to focus on taxis as a mode of transport for people with disabilities is due to the proportion of trips taken by disabled adults with taxis or minicabs as their primary mode of transportation is 2.2%, compared to 1.1% for non-disabled adults, and disabled adults take an average of 55% more trips using taxis or minicabs per year [9].

As such, the contributions of this paper are as follows:

- A comprehensive study that identifies crucial gaps in the existing literature and highlights the need for further research and development to ensure that autonomous taxi services are fully accessible to people with disabilities.

- Through rigorous analysis, our research team has identified key areas where further study is needed to understand the impact of autonomous taxis on people with disabilities. We have emphasized the importance of considering the entire ecosystem of autonomous taxis, including the onboarding and offboarding processes, to ensure that all passengers with special requirements can safely and comfortably use these services.

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- Our research also underscores the urgent need for a broader scope of disabilities to be considered in future studies, as current research focuses mainly on physical disabilities. By expanding our understanding of the needs and preferences of people with disabilities, there is scope for work towards creating a future where autonomous vehicles and services are truly inclusive for all.

- As one of the first studies of its kind to focus specifically on the United Kingdom, our research is poised to have a significant impact on the development of autonomous vehicle technology and accessibility services in this region with a focus on specific user groups to meet consumer expectations and enhance customer experiences.

- The research outcomes represent a pioneering and fundamental contribution, laying the groundwork for future explorations into emerging technologies like eVTOL in Urban Air Mobility (UAM). These insights are particularly significant as they reveal commonalities in user perceptions and challenges across these innovative transportation modes.

II. BACKGROUND

Although one of the often-stated aims of AVs is to increase transport accessibility for citizens [10], there remains a distinct lack of research on understanding how to achieve this for certain target groups, such as people with disabilities [11]. Disability, as currently understood in vehicle and policy design, tends to focus predominantly on physical disabilities, while the spectrum of disability range is quite diverse and complex, indicating a need for deeper research. In the UK, one of the benefits envisioned from AVs is increased access for specific target groups and states that in-depth understanding is required for ease of access for people with disabilities [11]. A study in Texas investigated the perspectives of people with disabilities and public transit agencies regarding the potential of AVs as a transport option [12]. The researchers conducted focus group sessions with participants from both groups to gather their opinions and insights. The study found that while some participants believed AVs could provide more independence and accessibility for people with disabilities, others had concerns about safety, reliability, and affordability. Public transit agencies expressed interest in exploring the use of AVs for first/last mile services but emphasized the need for regulations and standards to ensure safety and accessibility. Another US-based study analysed the gaps and opportunities in accessibility policy for on-demand micro-transit and paratransit services using Avs [13]. The authors argue that while AVs could provide more flexible and efficient transportation options, there are still concerns about accessibility and equity. The study concludes that policymakers need to address these issues and develop comprehensive policies to ensure that AVs are accessible and equitable for all users, including those with disabilities. A further US-based study explores the mobility challenges and perceptions of individuals with physical disabilities towards AVs. The researchers conducted surveys and interviews and highlighted the importance of including these specific target groups in the development and implementation of AV technology to ensure that it meets their mobility needs [14].

We live in hypermobile societies where being mobile has a relationship with the quality of life [15], along with the requirement to stay active and well-connected with friends and family, shops and services. A study that captured perspectives from 385 respondents with mental health conditions, determined why they choose or choose not to travel [16] in the United Kingdom. It was observed that 30% of the respondents were unable to get jobs as a result of accessibility issues related to transportation. Furthermore, it has been shown that social isolation as a result of reduced transport access is taking a toll on the mental health and wellbeing of more than two-thirds (70%) of people with disabilities, while 40% report an impact on their physical health [17]. Further research and development are needed to ensure that AVs and services meet the needs and preferences of people with disabilities [18]. Brands must recognize the importance of the disabled community, which constitutes 22% of the UK population, as indicated by the Family Resources Survey 2022 [19]. In the past decade, the proportion of the population reporting a disability has risen from 18% to 22% and is expected to go higher in the coming years. The prevalence of disability is positively associated with age: nearly 9% of children in the UK had a disability in 2020/21, while 21% of working-age adults and 42% of adults over State Pension age had a disability. Among individuals aged 80 and above, most reported having a disability, with a prevalence of 59%. Disabled adults are less likely to take trips and more likely to reside in households without access to a car, with 28% of disabled adults living in such households, as opposed to 15% of non-disabled adults [20].

Based on a review of the literature, studies on AVs and disabilities have primarily been conducted in the United States, with little research in the United Kingdom. Additionally, there is a lack of research on the impact of ride-hailing services, such as autonomous taxis, on people with disabilities. The studies that do exist focus mainly on physical disabilities, with minimal attention given to the wide spectrum of disabilities that are present which could impact an individual's day-to-day activities. Finally, a gap in the literature is also the limited focus on the entire ecosystem of autonomous taxis, including the onboarding and offboarding processes for passengers with disabilities and only concentrates on the in-vehicle conditions. Recent studies also suggest that further research and development are needed to ensure that automated vehicles and services meet the needs and preferences of people with disabilities [18]. The present study aims to fill these gaps in the existing literature and investigate the determinants that would enhance the accessibility of autonomous taxis. Specifically, the study aims to address two research questions: (1) What is the influence of individuals' previous experiences with traditional taxis on their expectations of autonomous taxis regarding disability accessibility? and (2) To what extent does the autonomy of self-driving taxis play a significant role in the perceived increase in the freedom of travel?

III. Research Methodology

A. Inclusion Criteria

In this study, the definitions of disability have been sourced from the Disability Act [21] in the United Kingdom, with a specific focus on disabilities impacting mobility in individuals' day-to-day lives. Based on this, organisations representing charities and special interest groups operating in the UK were shortlisted and approached for participation in this study. Members of each organization who were responsible for engaging with policy-level change makers, which included campaigners, spokespeople, and drivers of organisations that support people with various disabilities were contacted via email and phone calls and recruited based on their willingness to participate. To be eligible, participants had to be above 18 years of age and act as spokespeople for a UK-based organisation, lobbying local authorities and the government on behalf of their members.

The participants consisted of a wide range of designations of policy-related senior roles, including directors, assistant directors, human resources, project managers, development officers, project assistants, and self-advocacy group support workers. These individuals have a broad understanding of their members' needs and challenges and represent the wider views of people with disabilities, making them a strong voice for policy-level changes and adjustments. The study also included several types of organizations, such as those working with specific disabilities, including visual, sensory, and hearing impairments, mental health, learning disabilities, cerebral palsy, and pan-disability. Additionally, there were interviewees from advocacy groups, university-led disability departments, and government organizations. In total, 39,079 voices were represented by these organizations, providing a robust representation of the needs and challenges faced by their members impacting mobility in the UK. By collecting information from a range of organizations, this study provides insight into the lived experiences of individuals with disabilities and their support networks.

B. Data Collection

Thirty-two 60-minute semi-structured interviews were conducted with participants from January to April 2023. The data collection through interviews continued until reaching a point of data saturation, wherein no novel observations, findings, or perspectives were identified from the participating individuals. To accommodate the needs of the participants, telephonic and online interviews were conducted on Microsoft Teams. Participants were given the option to terminate the interviews if they felt triggered in any way, and the consequences were explained. The study anticipated that the participants may or may not have had any specific disabilities. During the interviews, it became apparent that individuals with disabilities may have more than one disability. For instance, a person with a learning disability may also have ADHD (attention deficit hyperactivity disorder), or an individual with visual impairment may also experience mobility difficulties. Table I shows the presence of disabilities among the interviewees.

C. Data Analysis

Interviews were captured and then transcribed using Microsoft Word and Excel. The interviewees were asked to cross-validate the summaries to minimize the risk of missing important information. Once received, individual data with common identifiers were deleted, and a combined analysis was performed to understand the specific themes. A reflexive thematic analysis was used, following the six-step process suggested by Braun and Clarke's method [22] [23]. After identifying the core themes, sentiment analysis using Azure Machine Learning software was performed to examine the strength of opinions. This is a method used in natural language processing, text analysis, computational linguistics, and biometrics [24]. The sentiment analysis identified the current experiences with traditional taxis as well as factors that influenced attitudes toward AVs, such as safety, trust, comfort, convenience, and concerns and expectations with the presence or absence of a driver [25]. Sentiment scores are assigned as strong, neutral or weak and are between 0 to 1 where 0 is a weak opinion and 1 is the strongest. These scores were then labelled as a positive or negative reaction to the statements of the interviews for this study. Similar studies were conducted using sentiment analysis to understand the impact of AV crashes on public perception [26] and to identify effective strategies for promoting AV adoption [27]. Although sentiment analysis has limitations, it is widely used and has shown an accuracy level of up to 85% [28].

D. Limitations

The participation methodology used an online study format, which offered several advantages such as the ability to engage with numerous organizations throughout the UK with extensive access and experiences in a limited timeframe [33]. However, there is room for improvement in the future, such as conducting in-person engagements to capture hard-to-reach communities. Additionally, there is the possibility of increasing the number of interviewees for participation. While the primary goal of this study was to involve spokespersons from organizations who possessed knowledge about their members' experiences, there is potential to gain a deeper understanding of specific concerns related to a particular disability by capturing the views of their members.

IV. Results and Discussion

Table II depicts the thematic analysis that identified specific themes and subthemes relating to the process of onboarding, in-vehicle conditions, and offboarding. The analysis was based on participants' experiences with both traditional taxis and how autonomous taxis could potentially improve or worsen these experiences and views on the

TABLE I : PRESENCE OF DISABILITIES OF THE INTERVIEWEES
(SEVERAL PARTICIPANTS HAD MULTIPLE CONDITIONS)

Disability	Count	Disability	Count
Mobility	5	Blind	2
ADHD	1	Partially Sighted	1
Hearing	2	Learning Disability	4
Mental Health	2	Autism	1
Cerebral Palsy	2	No Disability	5
Dyslexia	1	Not Declared	6

TABLE II. THEMATIC SCORE STRENGTH ANALYSIS FOR AUTONOMOUS TAXIS. SUBTHEMES ARE GENERATED FROM OVERLAPPING MAIN THEMES

Themes	Factor	Concern	Expectation	Sentiment Strength	Scaled Strength	Frequency Count	Frequency(%)
Onboarding	Cost	✓	✗	1.0	3.3	5	26.3
	Availability	✗	✓	4.3	14.7	18	94.7
	User Recognition/Verification	✓	✗	3.3	11.2	18	94.7
	Freedom of Travel	✗	✓	5.5	19.0	19	100.0
Sub Theme 1	Infrastructure	✗	✓	4.0	13.7	5	26.0
	Access	✗	✓	3.2	11.0	13	70.0
	Personalised HMI	✗	✓	2.6	9.0	12	63.2
In-vehicle	Safety	✓	✗	2.0	6.8	5	26.3
	Reliability	✓	✗	2.3	7.8	6	31.6
	Trip Customisation	✗	✓	3.1	10.7	12	63.2
Sub Theme 2	Accessible Payments	✗	✓	1.2	4.1	5	28.3
Offboarding	Lost and Found	✓	✗	0.8	2.6	2	10.5
	Customer Services	✓	✗	1.0	3.4	6	31.6
Sub Theme 3	Safe Parking	✓	✗	2.3	7.9	15	78.2
Sub Theme 4	Driver's Presence	✓	✗	4.2	14.4	13	68.4
	Assistance for Specific User needs	✓	✗	1.5	5.2	16	86.0

priority for future research and design for specific target groups to be truly inclusive. The ordering of themes represents the complete end-to-end journey of a passenger, from booking a vehicle through to reaching the destination and offboarding. The headings of the columns for each theme are defined as, Factors: These are the specific aspects or categories in the themes and subthemes being examined, such as onboarding, in-vehicle, offboarding, or driver-related factors while using an autonomous taxi. Focus for future research and design for specific target groups to be truly inclusive. Concern: This column indicates the specific concerns or issues associated with each factor based on the results of the sentiment scores. Expectation: It represents the desired or expected feature for each factor related to the usability of autonomous taxis; Sentiment Strength: This shows the summation of sentiment strength from Azure Machine Learning sentiment analysis associated with factors based on the interview responses; Scaled Strength: It represents the original sentiment strength multiplied by the sample size for proper visualization in Fig 3; Frequency Count: This indicates the number of times a particular concern or factor was mentioned in the interviews; Frequency (%): It shows the percentage representation of the frequency count.

A. Thematic Analysis for Autonomous Taxis

Fig. 1 presents the key themes and subthemes derived from the analysis, emphasizing crucial factors for people with disabilities using autonomous taxis. The themes are for specific events such as getting into the vehicle, considerations inside the vehicle and getting out of the vehicle. Whereas, the subthemes are the transition stages. While previous studies focused on in-vehicle accessibility, this analysis uncovered broader concerns regarding onboarding and offboarding
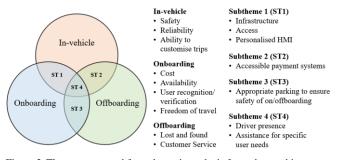
processes. Notably, the presence of a human driver and availability of assistance for specific conditions emerged as significant concerns, differing from negative experiences with traditional taxis where driver attitudes and behaviour were the primary issues (75.9% reported negative experiences related to biases, pick-up/drop-off, and availability). The analysis highlights the criticality of human assistance and the presence or absence of a driver across all journey phases. Concerns include hurried exiting, limited time for safe disembarkation, manual strapping of wheelchair users, and the need for assistance in wheelchair assembly/disassembly. This indicates the importance of addressing these factors to ensure a positive experience for people with disabilities using autonomous taxis from end to end. The thematic analysis sheds light on the broader considerations beyond in-vehicle accessibility, providing valuable insights for the design and improvement of autonomous taxi services to meet the unique needs of this user group at a holistic ecosystem level.

B. Traditional Taxis versus Autonomous Taxis

Fig. 2 presents a radar diagram of a comparative analysis of the sentiment strength scores of the themes between traditional taxis and autonomous taxis. This analysis revealed large differences between the concerns and expectations for traditional taxis and autonomous taxis. A high sentiment score represents a positive response whereas a low sentiment score represents a negative response. For traditional taxis such as Ubers or Black cabs, the primary accessibility concerns were their availability (42.0%), increased waiting times (42.1%), and infrastructure (57.9%) such as wheelchair accommodation. Prosecutions in the past decade were

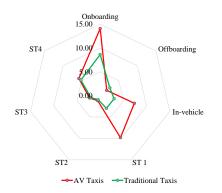Figure 2. Themes generated from thematic analysis for end-to-end journey for autonomous taxis

Figure 1. Comparative analysis of sentiment scores of themes between traditional and autonomous taxis

predominantly due to failing to accept bookings for assistance dogs or wheelchairs. Recent experiences have made this evident in the case of ride-hailing companies such as Uber where customers were refused access due to their disability [29] leaving passengers with traumatic experiences. Digital modes of booking also presented challenges for people with disabilities, particularly during peak hours. The primary concerns for traditional taxis were driver's behaviour and attitudes towards accessibility. Additionally, 63.1% of respondents reported incidents of biased behaviour experiencing discrimination from drivers when having a visible disability. The specific themes that emerged for autonomous taxis included cost, availability, user recognition, personalized human-machine interfaces (HMI), and the presence or absence of a driver. The primary concerns were onboarding and offboarding. There were also concerns regarding vehicle recognition for specific disabilities user needs, which occurred at a frequency of 94.7%. Although the most prominent concern for traditional taxis was driver behaviour, for autonomous taxis, respondents were more concerned about the availability of human assistance (85.9%) for specific user needs, and 68.4% felt that the absence of a human driver would not make their journey easier. Several interviewees stated that conversing with the driver added a social lightheartedness to their journey and helped with their loneliness and depression-related aspects. New research carried out by the national disability charity, Sense, has revealed that chronic loneliness affects almost two-thirds (61%) of disabled people, with this figure rising to 70% among young disabled people [17]. Therefore, Fig. 2 provides support in answering the research question, "How do current experiences of taxis impact the expectations of autonomous taxis for people with disabilities?".

C. Expectations and Concerns for Autonomous Taxis

Based on the thematic areas (Fig. 2), each factor was analysed as a concern or expectation of autonomous taxis. Table I was essential in answering the research question 'Is autonomy an important factor for self-driving taxis for people with disabilities?' As seen in Fig. 3, the primary anticipated advantage was enhanced freedom of travel. Thus, it was crucial to evaluate the extent to which autonomy affected this benefit [30]. To achieve this, Pearson's correlation was
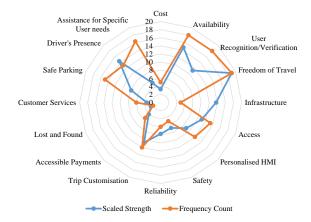

Figure 3. Scaled score and frequency count of factors in themes for autonomous taxis

employed to assess the association between sentiment scores obtained from datasets capturing opinions on the presence or absence of a driver in autonomous taxis and the perception of increased freedom of travel. Variable 1 'freedom of travel' and variable 2 'absence of a driver' revealed a statistically significant positive correlation $r (17) = 0.8$, p-value $= .001$. This indicates autonomous taxis could provide increased access to services without personal commitments or biases currently affecting the availability of traditional taxis. This can contribute to reducing welfare spending [35], with projected expenditures for disability benefits in Great Britain expected to reach £50.4 billion by 2027-28 [31]. Currently, individuals with disabilities face lower employment rates (53%) compared to non-disabled individuals (82%), and are more likely to be unemployed and economically inactive. Additionally, a higher proportion of working-age disabled individuals live in poverty (27%) compared to non-disabled individuals (19%) [32][34]. Current user experiences revealed various cases where drivers were unavailable due to personal commitments associated with domestic religious/cultural occasions. Therefore, autonomous taxis offer a potential solution to overcome the barriers faced by people with disabilities in accessing opportunities.

V. CONCLUSION

This study investigated people with disabilities' expectations and concerns regarding autonomous taxis compared to traditional taxis. Thirty-two semi-structured interviews were conducted with representatives from disability organizations, using reflexive thematic and sentiment analysis. This study addressed the limited accessibility progress for people with disabilities regarding autonomous taxis. It answered important research questions about the influence of traditional taxi experiences on expectations of disability accessibility in autonomous taxis and the autonomy of self-driving taxis contributing to perceived travel freedom. Shedding light on overlooked side effects of AV adoption, it emphasizes the significance of user-centric market research [36] for inclusive transportation options. The study highlights the critical role of human assistance and driver presence throughout all journey phases, crucial for AV deployment [18]. Disability, as currently understood in vehicle and policy design, tends to focus predominantly on physical disabilities, while the spectrum of disability range is diverse and complex, indicating a need for deeper research. It is crucial to incentivize automakers to include more user-centric engagements in their design processes. Collaboration, recruitment, and training with several organizations working with a range of complex needs for people with disabilities are essential to understand how specific user needs can be included to achieve the broader goal of accessibility. Policymakers must address issues related to passenger onboarding and offboarding, assistance with mobility aids, and passenger recognition and verification processes to ensure AVs are accessible and equitable for all users. Finally, the research provides a foundational basis for studying emerging transport technologies such as eVTOL in Urban Air Mobility [37] due to shared challenges.

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