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Challenges facing people with disabilities in private vehicular transportation in the United States of America

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Abstract

The majority of people with disabilities in the United States of America (US) are licensed drivers or use transportation modes based on private vehicles. Despite this, people with disabilities, including licensed drivers, still often encounter difficulties that limit their overall mobility and quality of life. Research about the problems with private vehicular modes facing people with disabilities remains sparse. Existing research suggests that some disabilities make driving impossible, while poverty often associated with disability makes owning and modifying vehicles to fit users' needs unaffordable. People with disabilities who cannot drive or cannot afford to own a vehicle may use rental cars or carsharing services, get rides from friends or family, or use ridehailing services or taxis, but car-oriented land use patterns and the higher costs of modified vehicles together may compromise the availability of these modes for people with disabilities. Better understanding of the challenges that people with disabilities face with these modes and of associated land use issues is critical for new modes & policies to sustainably improve the mobility of people with disabilities.

I. INTRODUCTION

Transportation is critical to the performance of many life activities, including but not limited to working, finding food, learning in school, socialization, entertainment, getting access to health care, engaging in religious or spiritual activity in groups, and performing basic civic duties [1–6]. People with disabilities [7] often face chronic challenges with transportation that can lead to frustration, depression, and isolation [3, 8–14], and can depress participation in jobs, interpersonal interactions, health care (as a patient), and voting among such people [1, 4, 11]. These challenges need to be addressed especially in countries like the United States of America (US), where the aging population (Baby Boomer generation) [1, 2, 15] and rising incidence of health problems like obesity [1, 11] lead to greater incidence of disability and consequent mobility limitations; the 2017 National Household Travel Survey (NHTS) by the US Department of Transportation (US DOT) [16, 17] shows that 25.5 million people in the US self-report travel-limiting disabilities.

Despite this urgency, there is much work to be done to improve understanding of the transportation needs of people with disabilities. We have addressed some aspects of this in a recent work under review, where we discussed the confusion caused by overly broad use of the word "accessibility", and introduced the concepts of availability, immediate usability, and cumulative usability. Availability refers to the spatial and temporal presence of a given mode, immediate usability refers to the ability of a person with a disability to independently use a mode at all when present, and cumulative usability refers to problems that people with disabilities may experience over an entire journey.

In this work, we use our definitions of availability, immediate usability, and cumulative usability to explain the benefits and challenges that people with disabilities face using private vehicular modes, especially in the context of car-oriented land use patterns. The 2017 NHTS shows that among the 25.5 million people with travel-limiting disabilities, which it defines as disabilities that lead survey respondents to report as causes of reduced travel, 56% are licensed drivers and 43% have ever asked others for rides because of their disability (and 20% of people with travel-limiting disabilities overall have done both). These mode use percentages are much larger than corresponding percentages of people with travel-limiting disabilities who use only public transit (12.5%), only paratransit (5.9%), or both services (5.5%). As we discuss in a recent work under review, these large percentages could be explained by the high levels of availability and cumulative usability that most people, including those with disabilities with immediately usable private vehicles, experience with private vehicular modes, as comfortable cars, forgiving road design, and plentiful parking together make it possible to travel comfortably from any origin to any destination in a private vehicle. Despite these benefits, many people with disabilities still experience significant problems with driving. As Fig. 1 shows, although significant fractions of people with travel-limiting disabilities are licensed drivers, they are significantly less likely than those without disabilities at every income level to be licensed drivers, and people with travel-limiting disabilities who are licensed drivers are significantly more likely to drive less than 5,000 miles per year across all vehicles than their peers without disabilities at every income level. While the 2017 NHTS does not break down miles driver per year more finely than 5,000 mile intervals, these results suggest that people with disabilities travel using private vehicular modes less than people without disabilities at each income level, and such a reduction due to disability is therefore not purely an income effect. Additionally, the 2017 NHTS shows that people are *less* likely to live in urban census tracts than in other census tracts regardless of disability, so people with disabilities who have higher incomes have lesser driver licensing and driving rates than the broader population likely for reasons more about disability than car-free urban lifestyles.

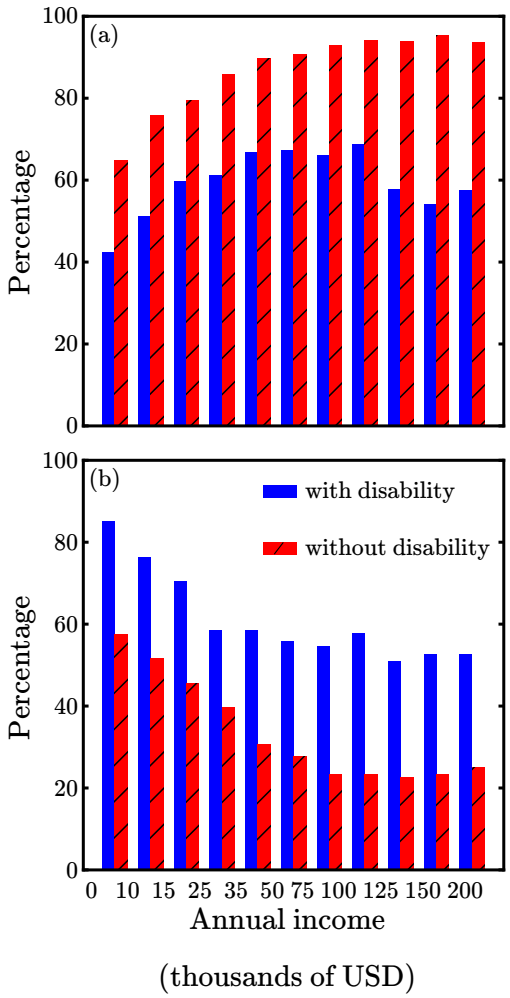

Figure 1. **Reduced driving due to disability is not just an income effect.** (a) Solid blue (striped red) bars show, out of the total number of people within a given income bracket with (without) disabilities, the percentage who are licensed drivers. (b) Solid blue (striped red) bars show, out of the total number of licensed drivers within a given income bracket with (without) disabilities, the percentage who drive less than 5,000 miles per year across all vehicles. For both plots, income brackets are listed between pairs of adjacent bars; the rightmost pair of bars in both plots corresponds to the income bracket of $200,000 or more. Statistics come from the 2017 NHTS.

These statistics suggest broad outlines but little insight into the problems with private vehicular modes facing that people with disabilities. Some prior works (Sec. II) have considered the problems that people with disabilities face when driving and when using some other private automobility modes, but these works have not considered specific problems in great depth. The rest of this work focuses on the problems facing people with disabilities who drive their own vehicles (Sec. III), use commercial carsharing services (Sec. IV), get rides from others (Sec. V), use transportation network company (TNC) services (Sec. VI), and use taxi services (Sec. VII), and those that may face people with disabilities using autonomous cars (Sec. VIII). We conclude with open questions for researchers and policymakers about the challenges that people with disabilities face with private vehicular modes (Sec. IX). Through this work, we will touch upon problems with availability and cumulative usability as they relate to each other and to car-oriented land use

Statistic: people with travel-limiting disabilities who…	Number (millions)
Are licensed drivers	14.4
Asked for rides from family or friends*	11.0
Used carsharing services (e.g. Zipcar)**	0.1
Biked†***	1.0
Biked††***	0.3
Used bike-sharing services (e.g. Zagster)†**	0.1
Walked†***	14.9
Walked††***	6.1
Used TNC services (e.g. Uber)**	0.8
Used public transit (buses, trains, or streetcars)**	4.6
Used special transportation services*	2.9

Table I. **Mode choices of people with travel-limiting disabilities.** All rows correspond to data from the 2017 NHTS [16], though some words have been changed slightly for clarity. All numbers are rounded to a single digit after the decimal point, and are representative (through weighting) of the general population in the US. Many individuals use multiple transportation modes in a given time period, so the numbers add to more than the total of 25.5 million people with travel-limiting disabilities.
*at least once ever
**at least once in the last 30 days
***at least once in the last 7 days
†for any trip purpose
††for travel and specifically *not* recreational exercise

patterns too.

II. PRIOR WORK

Rosenbloom in 2003 reviewed literature about the mobility needs of elderly people [18], discussing demographic trends, tripmaking patterns, safety issues, issues surrounding disability, and possible policy solutions. Rosenbloom in 2012 reviewed literature about the transportation patterns & problems facing people with disabilities [19], effectively distinguishing immediate usability from cumulative usability and availability (though not in those terms), and discussing accessibility concerns for specific transportation modes, including driving, getting rides from others, and using taxis. However, that works uses statistics about the problems with private vehicular modes facing people with disabilities taken from the 2002 US DOT National Transportation Availability and Use Survey (NTAUS) [19–22], which is out of date (given population changes) and does not include statistics about TNC use. Suen & Sen [23] have reviewed the mobility needs of elderly people, the challenges they face with different modes including driving, getting rides from friends or family, using taxis, and using local nongovernmental volunteer-run transportation services, and potential policy issues going forward. However, that work cites statistics that are even older than the 2002 NTAUS, its conceptual descriptions of the problems that people with disabilities face are only rarely connected with quantitative studies, and some of the stated qualitative problems (e.g. buses that are not immediately usable by people with physical disabilities) are also out of date at

Statistic: people with travel-limiting disabilities who…	Number who are licensed drivers (millions)	Number who are not licensed drivers (millions)	Ratio of those licensed to those not
Asked for rides from family or friends*	5.0	5.9	0.84
Used carsharing services (e.g. Zipcar)**	0.1	0.1	1.19
Biked†***	0.5	0.4	1.45
Biked††***	0.1	0.2	0.82
Used bike-sharing services (e.g. Zagster)†**	0.1	0.0	3.06
Walked†***	8.8	5.8	1.53
Walked††***	3.8	2.2	1.70
Used TNC services (e.g. Uber)**	0.4	0.4	1.21
Used public transit (buses, trains, or streetcars)**	1.5	3.0	0.49
Used special transportation services*	0.9	2.0	0.47

Table II. **Statistics of the mode choices of people with travel-limiting disabilities by driver licensing status.** All rows correspond to data from the 2017 NHTS [16], though some words have been changed slightly for clarity (but we hope this does not significantly change the meaning). All numbers of people are rounded to a single digit after the decimal point, and are representative (through weighting) of the general population in the US; all ratios are rounded to two digits after the decimal point, and are computed from exact (not rounded) numbers. The ratio of people with travel-limiting disabilities who are licensed drivers to people with travel-limiting disabilities who are not licensed drivers, accounting for all modes is 1.30. These statistics account for the fact that individuals may use many different transportation modes in a given time period.
*at least once ever
**at least once in the last 30 days
***at least once in the last 7 days
†for any trip purpose
††for travel and specifically *not* recreational exercise

least in the US. Koppa [24] has given detailed descriptions of typical modifications that drivers with disabilities install & use when driving and that vehicle riders with disabilities use as passengers. However, that work also cites modification technologies that are now several decades old, and we have not found newer works that review newer driver assistance technologies for people with disabilities with respect to the costs, capabilities, and typical problems with such adaptations. Klinich et al [25] have reviewed literature about wheelchair securement & rider restraint systems, including devices, standards, and computational models, but while that work has an eye toward autonomous vehicles, its focus on current work lies mainly in the context of large public transit buses. Beyond these, other academic works [11, 14, 26] consider broader forms of social exclusion due to transportation problems for people from different marginalized groups, but these works tend to mention problems for people with disabilities only tangentially and not in great depth.

III. DRIVING ONE'S OWN VEHICLE

We have discussed in recent work under review how car-oriented land use patterns in the US can make driving not only convenient but *necessary*. In this context, some academic re-

searchers [19, 27, 28] have pointed to the correlation of poverty with suburban living to argue for policies that ease the financial burdens of driving for poor people regardless of disability. For example, Blumenberg et al [29] have demonstrated that people who live in households with more than zero but fewer than one car per person travel at significantly greater distances & frequencies than those who live in carless households, and this remains true even if a large household must share one car. However, these works only address availability. They do not focus on problems facing people with disabilities, especially with respect to the high monetary costs & logistical difficulties of adapting vehicles to users' needs for immediate usability as well as other problems with cumulative usability.

People with travel-limiting disabilities who drive, irrespective of vehicular adaptations, often have different experiences than those without such disabilities. In particular, many people with travel-limiting disabilities, as well as many elderly people, alter their driving behaviors compared to typical non-elderly drivers who do not have travel-limiting disabilities [10, 19, 23]. These self-regulating behaviors for safety include but are not limited to driving less often in general, driving less often in bad weather, avoiding unfamiliar places, and driving slower than posted speed limits, any of which may reduce cumulative usability (as they have to do more with the course of a journey) and therefore reduce overall mobility for people with disabilities. A deeper qualitative study from Canada [30] describes a study participant using a wheelchair and an adapted vehicle, who is otherwise able to drive & get around independently, choosing to travel with someone else or to alternate locations in winter when snow may make it difficult to go in a wheelchair between the vehicle and a parking lot. Most of these works use statistics from the 2002 NTAUS, which was somewhat hampered by small sample sizes. More recent data from the 2017 NHTS shows that 5.4 million of the 14.4 million drivers with travel-limiting disabilities limit driving to daytime hours. Additionally, of the 25.5 million people overall with travel-limiting disabilities, there are 17.7 million who report reduced day-to-day travel [31], of whom 10.7 million are licensed drivers. Furthermore, of the 25.5 million people overall with travel-limiting disabilities, there are 6.8 million who report giving up driving altogether, of whom 6.0 million no longer hold valid driving licenses and 0.8 million still hold valid driving licenses (at the time of the survey).

Many people with disabilities require vehicular adaptations in order to drive, so some academic works consider the immediate usability of vehicles themselves and of any necessary modifications. The ADA and other laws relevant to people with disabilities do not require immediate usability of private vehicles for people who use wheelchairs or similar mobility devices, so almost all modifications to private vehicles to improve immediate usability are aftermarket. In fact, many modifications for immediate usability of private vehicles might be *illegal* until and unless new regulations (such as the Federal Motor Vehicle Safety Standards) specifically carve out exemptions for those types of modifications (such as disabling airbags in certain cases) [25]. The 2017 NHTS does not ask about vehicular modifications at all. By contrast, the 2002 NTAUS does ask about vehicular modifications, including not only ramps, lifts, and seating modifications for drivers in wheelchairs but also raised roofs, lowered floors, modifications to the air bags, modifications to the steering controls, modifications to the acceleration or braking mechanisms, and so on. Similarly, Koppa [24] explains that drivers with musculoskeletal disabilities typically need reconfigured steering hardware, drivers in wheelchairs typically need ramps or lifts as well as spaces in the vehicle to drive while sitting in a wheelchair, drivers with hearing disabilities typically need additional visual alert systems to compensate for the lack of hearing, and drivers with vision disabilities that are not so profound as to preclude driving entirely typically still need brighter exterior lights as well as interior controls with better lighting & contrast, with many of these modifications made after the fact. Although summary statistics from the 2002 NTAUS do not distinguish owners

of modified vehicles by the presence or type of disability, we believe it is safe to assume that the vast majority of people who have vehicles with such significant modifications would have travel-limiting disabilities. With this in mind, the 2002 NTAUS reports that 1.7 million people in the US have household vehicles with at least one of the substantial listed modifications (and we interpret the statistic that this question was "inapplicable" for 16.0 million people as meaning that those 16.0 million people do not own any vehicles), of whom 1.0 million people use such vehicles as drivers while 0.7 million people use such vehicles as passengers but *not* as drivers.

Typical costs of these modifications are substantial for most people with or without disabilities. The 2002 NTAUS reports that of the 1.7 million people in the US who have a modified vehicle, 1.4 million people were verified to have paid at least $400 for the modifications [32], although we emphasize that the statistic of 1.4 million may be unreliable due to the very small sample sizes involved in the 2002 NTAUS. That said, although the 2002 NTAUS distinguishes different people or organizations who may have paid for such modifications, it does not distinguish the respondent from family members, so it is not possible to use data from the 2002 NTAUS to determine how many respondents were financially incapable of paying for such modifications as individuals and depended on family members for help. These statistics are consistent with prior qualitative works [8, 9, 24] showing that the costs of modifications for people with disabilities can make personal car ownership financially impossible for such people, especially those who use wheelchairs. Finally, we point out that the 2002 NTAUS includes statistics about the reliability of such vehicular modifications, but these statistics themselves are unreliable due to the very small sample sizes involved, so we cannot make further quantitative claims about reliability issues.

There needs to be more systematic research, at the quantitative scale of the 2017 NHTS (as even the 2002 NTAUS, with over 2,000 respondents with disabilities, was hampered by small sample sizes), surveying drivers with disabilities to understand their needs, how many of them require vehicular modifications or restricted types of vehicles, how reliable those modifications are, and who pays for them. The last of those points is also relevant because, as prior works [19, 27, 28] have pointed out, the correlation of poverty to both disability and suburban living suggests that for poorer people in general, it may be necessary to promote policies that ease financial burdens of access to a private vehicle, but such policies would then need to account for the greater costs of making such vehicles satisfy immediately usable by drivers or riders with disabilities.

IV. CARSHARING AND RENTAL CAR SERVICES

The 2017 NHTS does not provide data about the use of multi-day rental car services, but it does show, as we present in Table I, that people with travel-limiting disabilities only minimally use carsharing services. Furthermore, we were unable to find any relevant literature about the use of rental car or carsharing services by people with travel-limiting disabilities and about the problems such people experience in those contexts. It is not immediately obvious to us why people with travel-limiting disabilities use rental car or carsharing services so much less than their peers without disabilities. We conceptually hypothesize three explanations that need not be mutually exclusive.

The first explanation has to do with the cumulative usability burdens that people with disabilities feel when driving even without the need for vehicular adaptations. In particular, self-regulatory behaviors discussed in Sec. III, including but not limited to driving less often in general, driving less in bad weather, avoiding unfamiliar places, and driving slower than posted speed limits, will likely not change those potentially travel-limiting behaviors when going between a rental car or carshare vehicle versus one's own vehicle. However, we were unable to find research validating

or disproving the notion that the cumulative usability burdens of such self-regulation can be correlated, let alone causally linked, to lesser use specifically of rental cars or carsharing services by people with disabilities.

The second explanation relates to the expenses of making modifications, which relates to the immediate usability of private vehicles. The large fixed costs of modifying private vehicles as discussed in Sec. III may be mitigated for people with disabilities if those vehicles are part of rental or carsharing fleets instead of being individually owned. These include modifications to allow people with certain kinds of disabilities to drive as well as those to allow people with broader forms of disabilities to ride more comfortably. Modifications for riders, like minivans adapted with ramps or lifts to accommodate riders in wheelchairs, may be relatively easy for rental car or carsharing services to provide as no further accommodations are needed for drivers, so ordinary drivers could use such vehicles even in the absence of riders with disabilities. However, modifications for drivers, like disabling of airbags or hand controls for drivers in wheelchairs, may be harder for such services to provide if they preclude drivers without disabilities from safely or easily using those vehicles.

The ADA requires car rental and carsharing services to have modified vehicles [33] but does not require specific types of modifications. This results in a broad spectrum of experiences for people with travel-limiting disabilities using car rental and carsharing services, with examples as follows. Enterprise CarShare [34] offers certain adaptations, namely hand controls, extended pedals, and spinner knobs, and claims that such adaptations are done through standardized modular installation procedures to allow for being undone later (so that drivers without disabilities can safely use the same vehicles). However, it explicitly does not offer vehicles with lifts immediately usable by drivers or riders in wheelchairs (and does not guarantee that adapted vehicles will accommodate a driver or rider in a wheelchair entering via a ramp), and instead gives information about another provider as a courtesy to customers. Ruvolo [35] has shown in a convenience sample survey of over 200 people with disabilities in the San Francisco Bay area that over $\frac{1}{3}$ of respondents have used carsharing services with vehicles modified for immediate usability by people with disabilities and has performed further qualitative interviews showing that many drivers with disabilities are interested in such services when available. Respondents in that study also alluded to previously available carsharing services in San Francisco that had vehicles adapted for people with disabilities. From web searches, we presume that respondents referred to the CityCarShare program [36, 37], which offered vans adapted to riders in wheelchairs, but we could not ascertain whether that service offered vehicles with adaptations for *drivers* with travel-limiting disabilities. In any case, CityCarShare was then sold to the company Getaround, but the vans that were immediately usable by people in wheelchairs were not part of that deal, because the grant from the Bay Area Rapid Transit that eased the financial & regulatory burdens for CityCarshare to buy & operate such vans forbade any other operators from using those specific vehicles at any time. We also note that the company Getaround offers peer-to-peer carsharing, which is an alternative to traditional carsharing in which drivers who are part of the carsharing network share their own cars with each other instead of using cars from a common corporate-owned fleet, but we could not find specific examples of peer-to-peer carsharing targeting people with travel-limiting disabilities. In any case, we could not find research validating or disproving the notion that the sparse availability of immediately usable adapted vehicles significantly depresses usage of rental or carsharing services by people with disabilities.

The third explanation relates to the implications of car-oriented land use patterns on the cumulative usability & availability of rental & carsharing vehicles for people with disabilities. Drivers with disabilities need to be able to get to rental or carsharing vehicles, typically without the help of

another private vehicle. This suggests that car-oriented land use patterns may burden customers, especially those with disabilities, with long & risky trips as pedestrians, cyclists, or public transit users to get to rental or carsharing facilities. Indeed, prior works [38, 39] have shown that all of the areas where traditional carsharing services (with vehicles stored in dedicated lots) have thrived so far have been in areas with good walkability & high-quality public transit services (though the converse, that good walkability & high-quality public transit guarantee success for carsharing services, does not necessarily follow), carsharing use is correlated with walking, and using street width as a separate proxy for walkability (where a wider street would correlate with less walkability due to the emphasis on high-speed driving) also shows a negative correlation between street width and carsharing business success. More recently, "dockless" carsharing services have emerged, in which drivers are allowed to park vehicles from these fleets in any legal parking space, not just authorized parking facilities (e.g. Zipcar). Examples include Car2Go, although its parent company suspended operations in the US in early 2020 [40], and Free2Move [41]. These companies have operated in restricted service areas in in moderately dense areas of select metropolitan regions in the US due to challenges in gaining usage and availability for people nearby when operating in sparse suburban or rural areas. In any case, these and other works have not discussed the extent to which people with disabilities may be disproportionately burdened by having to travel farther to reach vehicles in these services or whether such services could in any way reduce those first-/last-mile travel burdens.

We anticipate that these three hypothetical explanations are not completely separate but affect each other to some degree. In any case, all three of these hypothetical explanations need further research regarding travel behavior & public policy. The following example of a potential policy remedy comes from the discussion of the sale of CityCarShare to Getaround: given the burdens of buying & maintaining vehicles with substantial modifications for people (whether drivers or riders) with travel-limiting disabilities, any future deals to ease such burdens for other entities should attempt to the greatest possible extent to avoid situations where such vehicles may become effectively unavailable to most people with travel-limiting disabilities who would depend on those vehicles the most.

V. GETTING RIDES FROM FAMILY OR FRIENDS

We have shown in Table I that the 2017 NHTS [16] finds there are 11.0 million people with travel-limiting disabilities who have asked for rides from family or friends due to their medical conditions, though the 2017 NHTS does not ask further about the frequency of asking for such rides. Furthermore, when this statistic is broken down by driver licensing status, Table II shows that although there are 30% more licensed drivers than non-drivers with travel-limiting disabilities overall, there are 18% more non-drivers than licensed drivers with travel-limiting disabilities who ask for rides from family or friends due to their medical conditions, which means non-drivers are disproportionately dependent on rides from friends & family.

Despite this, there is very little research about the problems that people with travel-limiting disabilities face when getting rides from friends or family, or the frequency & reasons for doing so. We could only find work by Pyer & Tucker [12], who have performed qualitative interviews of teenagers in wheelchairs in different urban areas in the UK to show that such teenagers are often unable to get rides in the private vehicles of friends' families due to the need for expensive adaptations that are missing in those vehicles, and therefore report feeling embarrassment & social isolation stemming from missing out on being together with their more spontaneous peers. Additionally, Freund [42] has discussed how elderly people often rely on investment value of private

cars (even after they themselves stop driving) for financial sustenance, and on relatives/friends to drive them around in the cars that they themselves own but cannot drive anymore. Finally, Wasfi et al [43] have surveyed 114 people in Hennepin County, Minnesota with developmental disabilities, including cognitive disabilities, finding that although respondents who depend more on public transit are more likely to not make non-work trips than respondents who depend more on family or friends for rides, respondents who depend more on family or friends for rides are more likely to *want* to use public transit due to feelings of independence instead of feeling like a burden to family or friends in the context of transportation.

The study by Pyer & Tucker [12] makes clear that private vehicles not being immediately usable can make it hard for people with certain travel-limiting disabilities, especially people in wheelchairs, to spontaneously get rides with family or friends. Essentially, this is another manifestation of the problem in Sec. III regarding the lack of laws mandating immediate usability of private vehicles even for passengers with disabilities, let alone drivers. Furthermore, there are added problems with availability when depending on family or friends informally for rides due to scheduling or other conflicts.

The fact that so many people with travel-limiting disabilities have depended on rides from family or friends due to their medical conditions seems to demand more research about this mode. In particular, there needs to be research about what aspects of travel-limiting disabilities in the context of other possible mode choices make such people choose to ask for rides from family or friends, how often this happens, how often such people are unable to get rides from family or friends due to scheduling or other conflicts, and whether these issues lead to feelings of dependence and consequent resentment. For example, a survey of 2,917 online opinion panel respondents in California of age 55+ showed that 65% of elderly people who have Internet access (estimated to be 86% of all elderly people in California) would like to use TNCs to avoid asking friends or family for rides [44]. Such research about alternatives to getting rides from friends or family for people with travel-limiting disabilities should thus be extended beyond elderly populations. This would help to understand whether those other modes can be improved to improve mobility and the sense of independence among such people. On the other hand, there also needs to be more research about the frequency with which people with travel-limiting disabilities of any age group and with any disability feel hampered from traveling with friends or family for social reasons, and whether this leads to further feelings of social isolation. This would involve extending the work by Pyer & Tucker [12] to adults (not just teenagers) with travel-limiting disabilities who would like to travel spontaneously with family or friends specifically for social activities. Finally, we could not find research about the impacts of car-oriented land use patterns on the availability of rides from family or friends for people with disabilities, especially those who need immediately usable vehicles, and the aforementioned issues suggest the need for future research on this topic.

VI. TRANSPORTATION NETWORK COMPANY SERVICES

Transportation network companies (TNCs) constitute a relatively recent innovation, as the two main companies operating in the US, namely Uber & Lyft, were respectively founded in 2009 & 2012 (albeit under different names at those times). The basic idea of providing private ridehailing services separate from public transit, paratransit, and regulated taxi services is not new, as dollar vans & jitney services have existed for over a century, and the basic idea of connecting passengers making trips in the same direction is not new either, as carpool directories and similar services have existed for decades (particularly during the oil crisis of the 1970s). That said, TNCs have innovated by matching drivers & riders in real time via a smartphone app-based platform, bringing

together much larger networks of drivers & riders in that process, and centralizing the setting of prices while making them dynamically responsive to supply & demand across the network; as a result, TNCs provided rides to 2.6 billion passengers in the US in 2017, having grown rapidly from 1.9 billion passengers in 2016, and this has likely grown further since then until the COVID19 pandemic [45].

Despite this, statistics from the 2017 NHTS presented in Table I show that only 0.8 million out of the 25.5 million people with travel-limiting disabilities have used TNC services at least once in the 30 days leading up to the survey, and there are still many gaps in policy & practice with respect to TNCs serving people with disabilities. TNC services that are immediately usable by riders in wheelchairs are hard to find, as TNCs have argued that they are technology companies as opposed to mobility companies and are therefore legally exempt from relevant ADA regulations [33, 35, 46]. For people with cognitive disabilities, cashless payment for TNCs can simplify payment procedures for such people who are skilled enough at using the basic functions of a smartphone, but may introduce new barriers for people with cognitive disabilities that are more severe or for people with any disabilities who cannot afford a smartphone or credit card, given the negative correlation of disability with income [33]. Brewer et al [47, 48] in qualitative interviews of over a dozen people with vision disabilities as well as over a dozen TNC drivers who have experience giving rides to people with vision disabilities in the US, as well as Simek et al [49] in convenience-based online surveys of nearly 200 people with vision disabilities, have pointed to the following problems faced by people with vision disabilities when using TNC services. The immediate usability of such services' smartphone apps is improving over time, though the extent to which they comply with existing laws may still be questionable, but other operational characteristics of these services remain problematic. Many TNCs have not adapted the requirement to physically look for a car with a matching license plate to know it is theirs to the needs of such riders. Riders with vision disabilities depend on the kindness of drivers to tell them what is around them to assist with wayfinding (especially in unfamiliar areas), and to sometimes physically guide them around obstacles like construction zones. Riders with vision disabilities, and other disabilities too, are often concerned with identifying their disabilities before a TNC ride for fear of being exploited. All of these problems may generally be associated with immediate usability. With respect to TNC driver attitudes, the study by Brewer et al [48], as well as a study by Huff & Brinkley [50] which scraped over 1,200 comments from the social media website Reddit regarding the intersection of disability & TNC use, have found that many TNC drivers do not see assisting riders with disabilities as a burden, but some TNC drivers express concerns with accommodating service animals due to dander or odors or are simply scared of such animals. Drivers' fear of censure when admitting to denial of service or unequal treatment, either of which may constitute failures of availability or immediate usability of the service by riders with disabilities, may lead to underestimation of the frequencies of such behaviors.

Evidence for the effects of car-oriented land use patterns on the availability of TNCs (irrespective of disability) is mixed. Proprietary data from Uber [51] suggests correlations between TNC use & neighborhood density and claims that in car-oriented neighborhoods where people mostly use their own vehicles to get around, consequent demand & supply for TNCs are low. By contrast, prior academic work [52, 53] analyzing Lyft trips within Los Angeles County as well as Chicago have shown that Lyft effectively serves trips not only in the densest urban cores but also in sparser suburban and rural areas, people in households without their own vehicles tend to be heavy users of Lyft, and Lyft use correlates heavily with public transit stop density. We could not find discussions of similar issues for rides from family or friends or for taxi services. Furthermore, the only discussion that we could find of the disproportionate impact of such car-oriented land use patterns

on the availability of TNC services for people with disabilities has been work by Hassanpour et al [54], showing in Portland, Oregon in 2018 that TNCs are significantly less likely to provide rides at all to people in wheelchairs who need vehicles with immediate usability than those who do not, that these probabilities do not depend on characteristics of the built environment or socioeconomic status of residents in each neighborhood, that average wait times are significantly longer for people in wheelchairs who need vehicles with immediate usability than for those who do not, and that both wait times increase with decreasing population density; these are all problems with availability that come from differences in immediate usability of TNC vehicles. We could not find discussion of the disproportionate impact of car-oriented land use patterns on the availability of getting rides from friends or family or from taxis for people with disabilities.

Despite the challenges that have emerged for TNCs in serving the needs of people with travel-limiting disabilities, especially those that use wheelchairs and similar medical mobility devices as well as those that need assistance for vision-related tasks, people with travel-limiting disabilities are in many cases enthusiastic about the potential for TNCs to provide demand-responsive point-to-point mobility that may be cheaper or more convenient than alternatives like taxi or paratransit services. Ruvolo [35] has shown in a convenience sample survey of over 200 people with disabilities in the San Francisco Bay area that 72% of respondents have used standard Uber or Lyft services before, and 65% of respondents believe such services would be beneficial to their travel needs if some of the aforementioned problems could be resolved. In response, some cities are specifying & mandating minimum levels of accessible service from TNCs [46] and are also mandating training programs for TNC drivers to drive wheelchair-accessible vehicles & safely transport passengers in wheelchairs [55]. Some municipal & metropolitan public transit agencies are also partnering with TNCs as well as taxi companies who have vehicles immediately usable by riders in wheelchairs to more effectively provide paratransit services & serve riders with various disabilities [33, 56, 57], either specifically for riders with disabilities [58] or as part of broader efforts to make public transit services more responsive to travel demand & residential patterns [59]. That said, few systematic studies have been done about these innovative regulations & partnerships. One study [58, 60] has examined partnerships between MBTA paratransit services & TNCs in the Greater Boston area, finding that eligible paratransit riders who used TNC services through this partnership took 46% more rides than they did before, and reported significantly higher satisfaction with those rides, implying a large latent demand among people with disabilities for TNC services. However, this partnership has shown serious shortcomings in service for riders in wheelchairs or medical scooters (if those cannot be stowed in a trunk) due to a lack of vehicles that are immediately usable by riders in wheelchairs. Some TNCs like MUVE in northern Michigan have emerged to specifically serve people with various disabilities [46], but have mixed results with respect to long-term operational stability; for example, at the time of writing this paper, MUVE seems to no longer exist, as we were unable to find either a current website for its operations or official announcements or news articles about its putative closure. Finally, the study by Agrawal et al [44] has shown that elderly people who have Internet access do use TNC services at relatively high rates, but would prefer that TNC drivers be trained to deal well with elderly riders, telephone-based booking protocols be available as options, and TNC-specific cards be used to store fares as alternatives to credit cards.

VII. TAXI SERVICES

Taxi services have existed for decades, assisted by the ease of hailing a taxi ride on the street or by telephone. Taxi companies continue to serve the needs of people of varying incomes &

needs, including people of low income & people with disabilities. However, the high costs of taxi services may be prohibitive for many people with disabilities to depend on them for frequent trips, given the negative correlation of disability with income [1, 2, 4, 11, 17, 61]. Prior qualitative works [8, 9, 23] have reinforced these points about the intersection of disability, income, and taxi usage, though limited personal budgets do not necessarily deter people with mobility disabilities from using taxi services semi-regularly [57].

More severe challenges arise for people with physical disabilities, particularly people who use wheelchairs which cannot be folded or from which they cannot transfer into a car seat, who try to use taxi services. When taxi companies buy vans, the ADA requires that such companies choose vans that meet minimum standards of immediate usability for people with disabilities or demonstrate that other vans do not compromise the level of service for people with disabilities. However, the ADA does not forbid taxi companies from buying sedans which are not immediately usable by people with disabilities, even if they replace vans which were immediately usable, which subverts the intent of providing a minimum level of service for people with mobility disabilities [19, 20, 33, 62, 63]. This is compounded by the fact that taxi companies are often forced to bear the full costs of complying with local mandates to provide vehicles immediately usable by people in wheelchairs, and vans are much more expensive than and do not last as long as converted used police sedans that are more typically used as taxis [63]. There needs to be more investigation of how to make laws & policies more coherent as they pertain to taxi companies providing vehicles immediately usable by riders in wheelchairs. Furthermore, taxi drivers who are independent contractors can too often choose to deny service to people with disabilities, whether due to misguided preconceptions about their needs or a belief that their typically shorter trips would be less profitable [19, 63]. This is a problem with availability for people with disabilities, and there are not yet any relevant laws governing the behavior of taxi drivers interacting with people with disabilities who request rides. It is also notable that the study by Christie et al [63], which was funded by taxi companies, would openly admit that taxi drivers would so frequently deny service to people with travel-limiting disabilities. Finally, we point out that we were unable to find any research discussing problems that people with disabilities apart from mobility disabilities face when using taxi services, or quantifying the frequency of occurrence of specific problems (like lift or ramp failures or problems with driver attitudes) faced by people with disabilities in general when using taxi services, so that will need to be rectified in future research.

Finally, we note that while the aforementioned problems with taxi services have existed even before the advent of TNCs, the rapid growth of TNCs and concurrent decline in taxi ridership has been argued to have created financial pressures on the ability of taxi companies to provide services that are immediately usable by people in wheelchairs as well as those with other disabilities [35, 60, 62]. The argument is that because immediately usable vehicles are more costly to buy & maintain and because they do not generate enough revenue in places with car-oriented land use patterns, those are the first vehicles to be sold when a taxi company is looking to downsize, and such downsizing has been argued to be the direct result of the growth of TNCs (which, as mentioned earlier, often do not have immediately usable vehicles). However, these notions has not been made rigorous through systematic studies that are publicly available, so there needs to be more research about this.

VIII. POTENTIAL FUTURES FOR AUTONOMOUS VEHICLES

Although autonomous vehicles are not yet available for general consumer use, several recent works [61, 64, 65] have suggested that autonomous vehicles may be able to improve mobility for

people with disabilities when deployed in fleet settings where they may potentially serve many different people with different disabilities, provided those vehicles are designed to be immediately usable by people with different disabilities. These findings have been bolstered by a recent survey of adults with physical disabilities in the Midwest [66], who report significant challenges with transportation and express hope that those challenges can be mitigated with autonomous vehicles designed to be available, immediately usable, and cumulatively usable by them. However, if the present status quo dominated by individual ownership of vehicles persists, it seems likely that such vehicles will continue to not feature immediate usability by people with disabilities as there would be minimal demand from the vast majority of owners (who do not have disabilities), meaning people with disabilities will likely continue to face the prospect of costly aftermarket modifications. That said, people with other disabilities, like vision or cognitive disabilities, could potentially make use of such vehicles without as many costly aftermarket modifications and therefore benefit compared to the present status quo where such people are much less likely to be able to drive. In any case, a greater understanding of the policies that may lead to fleet ownership & promote ground-up (as opposed to aftermarket) design of immediately usable vehicles will be needed.

Considering higher-order effects, Milakis & van Wee [67] have discussed how shared or private autonomous vehicles could lead to further concentration of activities in urban areas with appropriately modified policies, leading to increasing real estate costs, or further dispersal of activities in suburban areas with status quo policies, leading to increased transportation costs; without additional appropriate policies, these outcomes could harm poorer people, and people with travel-limiting disabilities in turn given the correlation of disability with poverty. However, that work does not specifically consider the intersection of land use, income, and disability, and only considers the effects of autonomous mobility on people with disabilities in the context of the aforementioned issues with immediate usability. Thus, there needs to be more research about the higher-order effects of autonomous mobility under different ownership/service models on the mobility of people with travel-limiting disabilities, considering changes to land use, air quality, and other factors.

IX. DISCUSSION

We have shown in this work that the majority of people with travel-limiting disabilities are licensed drivers, but a near-majority of people with travel-limiting disabilities do not drive, and those people depend on rides from friends or family to a much greater extent than those who do drive. Furthermore, people with travel-limiting disabilities do not use carsharing, taxi, or TNC services that much, but have expressed interest in using such services more for greater convenience or lesser costs, if those vehicles could be more immediately usable and also more easily available in their neighborhoods. We have also shown that people with travel-limiting disabilities do face many challenges when using modes based on private automobility, including driving their own vehicles, depending on family or friends for rides, using carsharing services, and using taxi or TNC services, but details of these challenges need further study. These challenges raise questions relevant to basic research about the travel habits of people with travel-limiting disabilities, which we list below.

- How many people with disabilities drive vehicles that are adapted to their needs, what are those needs, what are those adaptations, how expensive are those adaptations, how reliable are those adaptations, and who pays for them? (The 2002 NTAUS [19–22] has some older

data, but newer statistics are needed, while the 2017 NHTS [16] does not distinguish whether the respondent or a family member pays for such modifications.)

- How many licensed drivers with travel-limiting disabilities never or rarely leave their homes, and why?
- How often do people with travel-limiting disabilities use traditional rental car services?
- How do the typical adaptations in carsharing or rental car service vehicles for people with travel-limiting disabilities compare to the typical adaptations in the vehicles that people with travel-limiting disabilities own?
- How often are adapted vehicles in carsharing or rental car services used by people *without* travel-limiting disabilities, and how easy is it for people without travel-limiting disabilities to use vehicles with such adaptations?
- In peer-to-peer carsharing services, how easy is it to share one's own vehicle with adaptations, or for a different person with a travel-limiting disability to use such a vehicle?
- How often are adapted vehicles in carsharing or rental car services used by people with travel-limiting disabilities as drivers versus as passengers?
- How often do people with travel-limiting disabilities depend on rides from family or friends, and why do they choose to depend on others for rides?
- How often do people with travel-limiting disabilities who depend on rides from family or friends experience scheduling conflicts on the part of the driver, and how does this correlate with the frequency of getting rides from a given driver?
- How often do people with travel-limiting disabilities want to share rides with family or friends in social contexts (whether in private vehicles or in other specified publicly-available services) but cannot due to problems with immediate usability of vehicles?
- To what extent can the decline of taxi services with vehicles immediately usable by people in wheelchairs be pegged to the rise of TNCs that typically do not have such vehicles?
- What might be the higher-order effects of autonomous mobility under different ownership/service models on the mobility of people with travel-limiting disabilities, considering changes to land use, air quality, and other factors?

Challenges with private automobility also raise questions relevant to policymaking and interpretation of existing policies, which we list below.

- How should policies that promote automobility (particularly vehicle ownership) among poor people, especially in suburban & rural areas, account for the different needs of people with disabilities?
- How should policies be constructed to avoid liquidating vehicles immediately usable by people in wheelchairs from carsharing services, taxi services, and TNCs?
- What policies could expand the availability of centralized carsharing facilities for people with travel-limiting disabilities in sparser suburban or rural areas?

- What new laws may be required to ensure that taxi companies & TNCs actually provide services immediately usable by people with disabilities, with features including but not limited to wheelchair accommodation, app design, vehicle identification, and accommodation of service animals, assuming they continue operating as businesses separate from each other and from paratransit services?

- What policies should be in place to ensure immediate usability of autonomous vehicles by people with disabilities, whether those are owned by fleets (in which each individual vehicle may be more likely to see at least one use by a rider with a disability) or by individuals (in which each individual vehicle is far less likely to see at least one use by a rider with a disability)?

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1. Search terms and scope

As this review is primarily concerned with the context of the US with respect to disability protections & transportation systems, we exclusively consider English-language academic journal articles, and we primarily focus on those papers which discuss issues in the context of the US, with lesser consideration of papers in the context of Canada, Europe, Australia, or New Zealand due to the numerous cultural & political differences outweighing the similarities, and still lesser consideration of journal articles in the context of other countries. We primarily used the search engines Google (with some results biased from searches from an IP address in Rockville, Maryland, and other results biased from searches from an IP address in Davis, California), Google Scholar, and DuckDuckGo to conduct our analyses. Our general search terms (in which the outer quotation marks simply demarcate the search terms, while any inner quotation marks are to be used literally as part of the search terms) included but were not limited to "disabled transportation review (paper OR article)", "disab* accessible housing mismatch transportation", "disab* pedestrian", "ADA requirements for public streets", "ADA blocking sidewalks", "Accessibility guidelines for pedestrian facilities in the public right-of-way shared use paths", "disab* (bicycle OR bicyclist OR bicycling OR cyclist)", "disab* public transit", "disab* paratransit", "disab* ("transportation network company" OR "transportation network companies" OR ride-hail OR ride-hailing OR ride-hail OR ridehailing OR ridesource OR ridesourcing)", "disab* "community transit"", "disab* (taxi OR taxicab)", "disab* (drive OR driver OR driving)", "suburbanization of poverty", "suburbanization of poverty transportation", "suburbanization of poverty disab*", "suburbanization of poverty transportation disab*", "carsharing spontaneity", "bikesharing spontaneity", "micromobility spontaneity", "wheelchair van drive", and "wheelchair accessible vehicle", we performed other specific searches as relevant for materials not in peer-reviewed academic journals cited elsewhere in this work, and we used citation chains in the articles we found to look for other articles as appropriate. Finally, we point out that this review focuses on local ground transportation, so discussion of air transportation (at any distance), long-distance bus & train services, and long-distance car rides will be outside of the scope of this work.

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