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Challenges faced by people with disabilities in public and active transportation systems in the United States of America

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Abstract

A significant fraction of people with disabilities in the United States of America (US) do not drive, and these people disproportionately use public transit and paratransit services compared to drivers with disabilities. Substantial research exists regarding not only the ease for people with disabilities to use public transit and paratransit services but also the availability of such services and the availability of nearby pedestrian infrastructure. However, much less research exists regarding the effects of shared micromobility services, car-free areas, and consolidation of public transit services on the mobility of people with disabilities. This systems-level thinking about not only first-order effects but also second- and higher-order effects is critical for the development of policies that more effectively address the mobility needs of people with disabilities.

Statistic: people with travel-limiting disabilities who…	Total (millions)	Fraction among licensed drivers	Fraction among non-drivers
Are licensed drivers	14.4	100.0%	N/A
Asked for rides from family or friends*	11.0	34.4%	56.6%
Used carsharing services (e.g. Zipcar)**	0.1	0.5%	0.6%
Biked†***	0.9	3.5%	3.4%
Biked††***	0.3	0.9%	1.4%
Used bike-sharing services (e.g. Zagster)†**	0.1	0.4%	0.2%
Walked†***	14.6	61.3%	55.2%
Walked††***	6.1	26.5%	21.5%
Used TNC services (e.g. Uber)**	0.8	3.0%	3.4%
Used public transit (buses, trains, or streetcars)**	4.4	10.1%	28.4%
Used special transportation services*	2.9	6.3%	18.7%

Table I. **Statistics of the mode choices of people with travel-limiting disabilities.** All rows correspond to data from the 2017 NHTS [16] (with wording lightly edited 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. 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

I. INTRODUCTION

Transportation is critical to many life activities, including work, education, socialization, entertainment, healthcare, religious activities, and 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, healthcare (as a patient), and voting [1, 4, 11]. These challenges must be addressed especially in 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 [16, 17] shows that 25.5 million people in the US self-report travel-limiting disabilities.

In this work, we focus on the problems that people with disabilities face with public and active transportation modes. Table I shows that a large fraction of people with disabilities do not drive, significant numbers of people with disabilities depend on public & active transportation modes, and non-drivers with disabilities are much more likely than drivers with disabilities to depend on public transit & paratransit services. In recent work under review, we have coined terms, namely availability, immediate usability, and cumulative usability, to categorize challenges that these modes present to people with disabilities. To summarize, availability refers to the spatial locations, times of day, and frequency of service characterizing a transportation mode; these characteristics are independent of disability. Immediate usability asks whether a person with a

disability can use a mode at all when present. Cumulative usability asks whether a mode that is present and immediately usable for a person with a disability excessively burdens that person with physical or mental stress, especially as the trip length increases, thereby potentially discouraging further tripmaking. We will use these terms consistently through this work.

The types of first-order problems with transportation facing people with disabilities are documented in detail for some modes but not for other modes, and the first part of this work will focus on such first-order problems. After summarizing relevant prior review articles and book chapters in Sec. II, we describe in Sec. III the considerable amount of research about the challenges facing pedestrians with various disabilities even in so-called ideal pedestrian environments and their needs for improvements to street lighting & furniture; however, little research exists about challenges in suboptimal weather conditions or topographies. We show in Sec. IV that little research exists about the problems facing people with disabilities when using bicycles and other forms of micromobility or about the challenges facing shared micromobility services in providing devices immediately usable by people with disabilities. We show in Sec. V the large amount of research about the broad categories of challenges that people with disabilities face when using public transit services contrasting with the relative dearth of research about the frequency of these problems occurring; we clarify that in this work, we consider public buses, bus rapid transit (BRT) services, and public trains, but not private buses or trains, public or private ferries, or private jitneys. The large amount of research about the broad categories of challenges that people with disabilities face with public transit services contrasts with the dearth of research about similar challenges in paratransit & similar services; we discuss these gaps, as well as the lack of research about who uses paratransit services, in Sec. VI.

In recent work under review, we have discussed the conceptual relations among availability, immediate usability, and cumulative usability. Characteristics of different public and active transportation modes connect with each other and with broader land use patterns. These are second-order challenges with public and active transportation modes facing people with disabilities, and they are much less studied than the aforementioned first-order challenges, so the second part of this work focuses on those challenges. In Sec. VII, we show that there has been some research about the ways that the lack or poor quality of pedestrian infrastructure can depress public transit use among people with disabilities, but policy solutions to this problem have been lacking. In other cases, basic research about second-order challenges for people with disabilities is anecdotal at best & conjectural at worst. We discuss such gaps specifically regarding the effects of micromobility services on walking in Sec. VIII, the effects of consolidating or replacing bus routes in Sec. IX, and the effects of car-free zones in Sec. X. We conclude in Sec. XI by pointing out where further research is needed and where consideration of new policies might be justified.

II. PRIOR WORK

Review articles about people with disabilities in transportation seem disproportionately to focus specifically on children [11]. In the context of the US, this may be because legal mandates for public schooling for all children and for children with disabilities to have equal access to school buildings, integrated classrooms, school transportation, and other school features, together ensure greater visibility of school transportation for children with disabilities. This contrasts with the lack of similar mandates for adults with respect to specific places of employment, socialization, or entertainment. Prior review articles [6, 18–21] about transportation for children with disabilities, primarily but not exclusively in the context of school, have referred to other works that consider the effects of the built environment, obesity, parental attitudes toward safety, and other demographic

characteristics in addition to inherent issues associated with disability. Those works raise concerns about policymakers' neglect of the *desires* that children with disabilities have for transportation and excessive reliance on the individual biological (as opposed to biopsychosocial) model of disability, as such a view justifies onerous behavioral training for such children without considering more equitable systemic improvements. Furthermore, those cited works consider issues in countries apart from the US and acknowledge the subtleties in applying lessons from one country to another.

Some review articles and books have gone beyond the specific context of children. Of these, some have focused on issues specific to particular modes, such as wayfinding by pedestrians with disabilities [5], the role of the built environment in encouraging people with disabilities to improve their mobility by using pedestrian or public transit facilities [15], specific challenges that people with disabilities face when using public transit or paratransit as well as transportation network companies (TNCs) or other new mobility services [22], challenges facing public transit users with disabilities across an entire journey (including pedestrian facilities) [23], and challenges in public transportation facing people with physical disabilities using mobility devices [24, 25]. Others have focused on the mobility needs of elderly people in the context of disability [26, 27] as well as people with disabilities of all ages [28] using travel data and policy analyses for various modes. Still other works [11, 14, 29, 30] have considered 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. WALKING

Walking is unique among modes of transportation, because it is the only mode whose general characteristics of immediate usability depend only on fixed stationary infrastructure [31]. Walking shares some characteristics of availability with driving one's own vehicle: in principle, anyone without a disability can choose to walk on any surface at any time of day, without being constrained by fixed schedules or routes. Going further, there is no worry about parking. However, as we discuss through this work, the nature of fatigue in the human body (in contrast to the ease of refueling a vehicle) along with the large distances created by car-oriented land use patterns together mean that the range of typical destinations that can feasibly be reached by walking is often far less than the range of destinations that can be reached by modes based on private automobility. These are problems with cumulative usability that are somewhat separate from immediate usability, as such disparities exist even with high-quality pedestrian infrastructure (though such disparities may widen further for low-quality pedestrian infrastructure). Pedestrian infrastructure usually refers to sidewalks, while the quality of sidewalks may be characterized by traits including sidewalk width, material choice, slope, bumpiness, and state of repair. We will also discuss how other relevant aspects of static pedestrian infrastructure for walking include benches to take rest, adequate lighting, and clear signage for proper wayfinding, yet these have often been ignored in policy debates about pedestrian infrastructure as a whole.

As shown in Table I, the 2017 NHTS has found that of the 25.5 million people with travel-limiting disabilities in the US, in the 7 days prior to the survey, 14.9 million made at least one walking trip, and of these, 6.1 million people made at least one walking trip purely for travel (and not for exercise). That said, the survey does not clarify whether respondents should count trips using wheelchairs or medical scooters as "walking" trips. When analyzing this by driver licensing status, licensed drivers with travel-limiting disabilities are more likely to walk than non-drivers with travel-limiting disabilities, and this remains true when considering walking trips purely for

travel. When analyzing this by age (irrespective of driver licensing status), statistics from the 2017 NHTS show that in the 7 days leading up to the survey, among people with travel-limiting disabilities, the percentages of people who made at least one walking trip were 65.4% of those of age 25 or less, 65.9% of people between the ages of 26-64, and 50.1% of those of age 65 or more. Rosenbloom [28] has cited similar, albeit older, statistics from the 2002 NTAUS [32–34], though with a few differences beyond those that have already been mentioned: the 2002 NTAUS asked about walking trips in the 30 days leading up to the survey, and it explicitly included trips made using manual wheelchairs or manual micromobility scooters but *not* motorized wheelchairs or medical scooters. The greater likelihood of drivers with disabilities to walk than non-drivers with disabilities may seem counterintuitive at first, as one might expect that non-drivers with disabilities would be forced to walk more, while drivers with disabilities would rarely choose to walk if driving is an option. However, Rosenbloom [10, 28] explains that, at least among elderly people, it is far easier and more likely that a person might give up walking outside of the home before giving up driving, due to the lesser physical burdens and arguably lesser mental burdens, and therefore greater cumulative usability, of driving in one's own vehicle compared to navigating as a pedestrian in shared spaces. Those works as well as work by Suen & Sen [26] also point out that elderly people use walking as the second most common mode of transportation after driving their own car. In any case, although the habits of elderly people with travel-limiting disabilities may differ from those of younger people with travel-limiting disabilities, the 2017 NHTS shows that people of age 65 or older make up a significant minority (44.0%) of all people with travel-limiting disabilities in the US, so the habits of elderly people with travel-limiting disabilities with respect to driving & walking can easily have a significant influence on the overall statistics.

With respect to immediate usability and cumulative usability, various prior works discuss the experiences of people with various disabilities when functioning as pedestrians (whether physically walking unassisted or using an assistive mobility device including but not limited to a wheelchair, medical scooter, cane, or walker). Suen & Sen [26] have enumerated actions that people with disabilities in different neighborhood types (urban, suburban, or rural) must be comfortable doing for different modes of transportation, including walking, and a list of underlying problems with infrastructure, including with lighting or seating, that may compromise such actions. They have shown that although people who were at least 75 years old in the UK in 1996 made 34% of their trips by walking, a lack of safe paths & crossings may discourage people who may otherwise be physically capable of walking (or bicycling) in ideal conditions over short or moderate distances. They only briefly acknowledge variations in mobility due to adverse weather conditions. Prescott et al [5], in reviewing prior works about people with various disabilities in the pedestrian context, have found that people with cognitive disabilities tend to have a wide variety of abilities that are challenging to assess. They have also found that people with vision disabilities tend to rely on familiarity, audio cues, tactile cues, audio-tactile maps (which tend to work better than purely spoken directions), and companions, and struggle with complicated road crossing designs. They have further found that people who have hearing disabilities but do not have vision disabilities tend to have fewer problems overall but may encounter problems when sight lines are challenged (as may occur in complex intersection designs). They have additionally found that people with physical disabilities may face common physical barriers but to different extents due to the use of different assistive devices, and commonly face the challenge of walking quickly enough across a crosswalk. Broadly, they have also acknowledged the need for more studies of changes in the ability of people with disabilities to navigate pedestrian environments at different times of day & in different weather conditions. Park & Chowdhury [23], in reviewing problems that people with disabilities face with whole journeys on public transit, consider problems facing pedestrians

with disabilities, including lack of lighting, seating, and shelter, unsafe crossings, obstacles on sidewalks (including vehicles jutting onto them), and unwanted noise, but do not consider weather or topography. The only work we could find specifically about the effects of weather on pedestrian tripmaking by people with disabilities was by Ripat et al [35]; that work reports on three individuals using wheelchairs in Canada, which can qualitatively illustrate relevant problems but gives no insight as to how many people with different disabilities encounter similar problems.

Rosenbloom [28] has explained that the Americans with Disabilities Act (ADA) does not mandate construction of sidewalks where none were available before, and while it does mandate that any new construction fulfill certain requirements for immediate usability, these requirements have most often been narrowly interpreted to apply to curb ramps. One of the few exceptions cited in that work is a court ruling that the city of Sacramento, California must ensure other parts of new sidewalks (beyond curb ramps) be immediately usable and arguing that such a mandate is consistent with the spirit of the ADA. Even for curb ramps, violations of legally-mandated immediate usability are routinely found & reported in complaints [36]. Additionally, it is not clear whether even accepted standards for curb ramp design may in practice pose problems similar to those posed by bus ramps for people in manual wheelchairs [9].

A few works have gone beyond simply cataloging problems with immediate usability for pedestrians with disabilities and have further directly connected such problems to problems with cumulative usability and tripmaking for such people. Vale et al [37] have conducted detailed analyses of sidewalk, road, crosswalk, and curb ramp conditions in the urban core of Lisbon, Portugal. In assuming that people with physical disabilities tend to require more sidewalk space & proper ramps, they have found that problems with design, street furniture, and other barriers in pedestrian infrastructure, constituting problems with immediate usability, create significant disparities in place-based accessibility for pedestrians with physical disabilities compared to those without physical disabilities. Clarke et al [38] have analyzed data from the Chicago Community Adult Health Survey from 2001-2003, focusing specifically on people with physical disabilities due to problems with lower extremities. They have found that differences in tripmaking difficulty for pedestrians with mild health problems compared to those without health problems were statistically insignificant & uncorrelated with pedestrian infrastructure condition, but such differences for pedestrians with moderate & severe health problems compared to those without health problems were statistically significant & deepened with more severe states of disrepair. Their work structurally treats such failures of pedestrian infrastructure as social causes of reduced tripmaking outside of the home. Clarke et al [39] have also analyzed data from the 1986-2001 Americans' Changing Lives survey, finding across the US that living in a neighborhood with more car-oriented land use patterns, implying worse cumulative usability, or worse pedestrian infrastructure, implying worse immediate usability as well as worse cumulative usability, is significantly positively correlated with tripmaking difficulty for elderly people controlling for every level of health, income, and other characteristics. We note that the latter two works carefully distinguish individual health problems (acknowledging that these could be influenced by external factors too) from "mobility disability" as arising from the combination of physiological, psychological, and social factors, thereby avoiding the pitfalls of the medical model of disability.

The works cited in this section show, in the pedestrian context, that immediate usability is not a binary quantity; some barriers, like street furniture completely blocking a sidewalk, may broadly prevent the completion of a trip, whereas other barriers, such as potholes in the sidewalk, might prevent only some people with disabilities from completing a trip while others with disabilities may complete the trip with some delay, physical stress, and mental stress. Repeated instances of problems with immediate usability, such as many potholes spanning significant lengths of side-

walks, can present problems with cumulative usability, as the stresses from these problems experienced in longer journeys may discourage tripmaking. Broadening the legal scope of the ADA to cover not only the immediate usability of curb ramps but also the availability, immediate usability, and cumulative usability of sidewalks themselves will take time and sustained political action. Without such action, pedestrians with disabilities may continue to face the problems discussed in this section.

IV. BIKING AND OTHER FORMS OF MICROMOBILITY

We have shown in Table I, from the 2017 NHTS [16], that of the 25.5 million people with travel-limiting disabilities in the US, in the 7 days prior to the survey, 0.9 million biked at least once for any reason, of whom 0.3 million biked purely for travel (*not* for recreation), while in the 30 days prior to the survey, 0.1 million used bike-sharing services at least once. The 2017 NHTS does not directly ask about micromobility services, while the 2002 NTAUS [28, 32–34] does ask about "manual scooters" but does not clarify whether that term refers to micromobility scooters per se.

The main problem preventing people with travel-limiting disabilities from using bicycles & other micromobility devices, particularly in shared services, seems to concern the immediate usability of those devices, but existing literature addressing these questions is sparse. Wright [40] has reported on the rarity of finding micromobility devices immediately usable by people with physical disabilities. Ruvolo [41] has performed a convenience sample survey of over 200 people with disabilities in the San Francisco Bay area, showing that less than 10% of people with disabilities there currently use micromobility devices like bicycles or scooters, and a majority would not consider using such devices even if immediate usability problems with such devices could be resolved. That said, the latter result may be confounded by the possibility that compared to the current status quo, more systematic in-depth demonstration & training could better inform people with disabilities about how adapted micromobility devices could work for them. Furthermore, Brown & Taylor [42] do cite examples of large micromobility companies using a few adapted micromobility devices, but their analysis does not address whether it is financially sustainable for companies to keep such devices for many years. Questions of financial sustainability become especially vexing if the adaptations required for people with certain disabilities to use such devices ends up excluding people without disabilities from using those particular units.

Shared micromobility services are similar to carsharing services in that both types of services require the traveler to directly operate the vehicle/device, so as we discuss in a companion work, people with travel-limiting disabilities may require adaptations to the vehicle/device to make such operation easier. In addition to the challenges that carsharing companies face when trying to provide adapted vehicles or devices, shared micromobility services face two further challenges, which we describe as follows.

First, although it is possible for a carsharing company to offer vehicles adapted to riders with disabilities while assuming that there will be a separate driver who does not require such adaptations [43, 44], it is much rarer for bike-sharing companies to offer bicycles that have seats for passengers. Users who have tried to come up with their own solutions have faced disapproval from such companies [45]. We intuitively suspect that even when such solutions exist for bicycles, people with travel-limiting disabilities may feel less comfortable asking family members or friends to physically exert themselves by driving a bicycle compared to driving a car carrying both of them. Additionally, we suspect that two-person micromobility scooters may be impossible due to the small form factor.

Second, carsharing is often done with significant advanced planning due to the greater costs (per unit distance or time) of renting a carsharing vehicle and the lower density of available vehicles close to a person at any given location [46–49] (and while dockless carsharing systems may allow for greater spontaneity in travel, we have already discussed in a companion work that this is typically only viable in moderately dense urban areas where trips are likely to be shorter anyway). This is also reflected in how carsharing companies like Enterprise CarShare [50] can accommodate requests from people with travel-limiting disabilities by having such people get in contact with the company in advance. By contrast, many users of shared micromobility services (including bikesharing services) see spontaneity, effected by a profusion of devices, as a key feature [51–53]. Thus, if shared micromobility companies cannot develop devices that can accommodate all riders (whether through universal design or through modular adaptations), they will face tradeoffs between having a large number of adapted devices that most people without disabilities cannot use, in order to satisfy the desires of people with travel-limiting disabilities to use such devices spontaneously, versus having only a small number of adapted devices in a sea of devices that are not adapted, in which case people with travel-limiting disabilities would have to plan ahead & search extensively for adapted devices. In the latter scenario, people with disabilities would face problems with cumulative usability due to the disproportionate physical and mental stresses of having to walk much further to get to such adapted devices (which in some cases may arguably defeat the purpose of using shared micromobility instead of walking).

V. PUBLIC TRANSIT SERVICES

We have shown in Table I that the 2017 NHTS [16] has found that of the 25.5 million people with travel-limiting disabilities in the US, in the 30 days prior to the survey, 4.6 million used public transit services (excluding paratransit or other special services) at least once, of whom 3.0 million are not licensed drivers. Thus, although non-drivers with travel-limiting disabilities are much more likely than licensed drivers with travel-limiting disabilities to use public transit services, less than 20% of all people with travel-limiting disabilities use public transit. Despite this, and perhaps because it is easier to study aspects of publicly provided services compared to their private counterparts, we will show that there has been much greater emphasis in policy with respect to the immediate usability, and to some degree the availability, of public transit, and this is reflected in the academic literature too. In particular, we will show that many legal requirements as well as academic works address many individual aspects of using public transit services, including the provision of information, the payment of fares, navigation to buses or trains, boarding buses or trains, issues that may arise while on board buses or trains, and provision of alternative services (considered as modifications of regular public transit services, separate from paratransit).

Table II summarizes & categorizes prior works about challenges with public transit facing people with disabilities, based on broader issues, specific issues, which subgroups of people with disabilities are most likely to be affected, and whether the issues relate to immediate usability, cumulative usability, and availability. Our definition of availability is independent of disability, so these works' focus on issues most relevant specifically to people with disabilities relate more to immediate or cumulative usability. Additionally, most issues related to information provision or navigation are more relevant to people with cognitive or vision disabilities, while those related to boarding public transit vehicles are more relevant to people with physical disabilities, especially those who use wheelchairs or medical scooters. We supplement this summary with the following clarifications & caveats (in no specific order).

Broad issue	Specific issues	IU, CU, or A
Information provision	Apps [54–57]	IU (vision, cognitive)
	Printed materials [4, 10, 26, 28]	IU, CU (vision, cognitive)
	Signage, announcements [4]	IU, CU (vision, cognitive)
Fare payment	Bus fare payment machine design [58]	IU (physical, vision)
	Fare structures & policies [59]	CU (cognitive)
	Train station fare gates [60]	IU (physical)
Navigation	Bus shelter design [23, 55]	IU, CU (especially physical)
	Train station complexity [23, 55]	CU (especially vision, cognitive)
	Train station elevators [26, 32, 59, 61–64]	IU (physical)
Boarding	Bus ramp slope [4, 8, 9, 28, 60, 65]	IU (physical)
	Ramp placement relative to bus [58]	IU (physical)
	Bus lift breakages [59, 61]	IU (physical)
	Human dependence for train ramps or lifts [55, 62]	IU, CU (physical)
On board*	Spatial conflicts [8, 9]	IU, CU (physical)
	Unwanted attention, physical discomfort [8, 9, 60]	CU (physical)
	Mobility aid securement [24, 60, 61, 66]	IU (physical)
	Stop announcements [60, 61]	IU, CU (vision)
	Trust of bus driver [61, 67]	CU (especially vision, physical)
	Unwanted dependence on others [28, 55]	CU (especially physical, vision)

Table II. **Summary of prior work about public transit problems facing people with disabilities.** The third column categorizes issues in the second column by immediate usability (IU) preventing a rider with a disability from making a trip when the vehicle is present, cumulative usability (CU) discouraging a rider with a disability from making future trips due to cumulative physical or mental stresses, or availability (A), and parenthetically notes what subgroups of people with disabilities may be most likely affected by these issues; those with the word "especially" can also significantly affect other subgroups of people with disabilities not listed.
*The broad issue of being "on board" refers to buses; we could not find similar studies or accounts of such issues on trains.

- Although disability is negatively correlated with income, our consideration of fare payment issues is separate from broader questions about affordability. That said, this correlation means that public transit agencies' use of electronic fare payment systems could help people with cognitive or vision disabilities when paying fares but could more broadly hurt people with disabilities who do not have smartphones, bank accounts, or credit cards [22], though solutions like the Chicago Ventra debit card [68] have worked where implemented.

- Unsworth et al [25] have pointed out the lack of research about the immediate usability of light rail or tram *stations*, compared to heavy rail stations, for people using wheelchairs.

- Findings about failure rates of bus ramps or lifts are sparse and are mixed when they do exist, as some studies explicitly report rider satisfaction with ramps & lifts [4], other studies report frequent failures [8, 9], and still other studies imply the lack of such failures from the lack of such rider reports [28, 65]. This suggests the need for more systematic evaluation of bus ramps' & lifts' failure rates in real operational settings, given the ramifications for immediate usability of public transit by people with physical disabilities and given variations

in lift design [69, 70].

- Steinfeld [60] has recommended for physical safety that bus riders using wheelchairs face toward the back of the bus (as is more common in Europe). However, that same source acknowledges concerns about unwanted attention and physical discomfort. Therefore, there is a need for more research about whether having only bus riders in wheelchairs, and not other riders, face toward the back of the bus may exacerbate unwanted attention.

- Rosenbloom [28] as well as Steinfeld [55] have explained how general discomfort with the need for assistance on board public transit vehicles, or specific experiences leading to such discomfort, may lead people with travel-limiting disabilities to drive instead of taking public transit. This relates to cumulative usability, but it is unclear whether the need for assistance may be mitigated to a large extent with better design of vehicles (which in turn would improve immediate usability).

Beyond these clarifications & caveats, we also point to two gaps in literature & policymaking with respect to public transit for people with disabilities. These are about level boarding in buses and (separately) flexible public transit services in smaller communities.

A possible solution to the problem of boarding buses for people with physical disabilities may come in the form of level boarding, in which the floor of the bus is aligned with the floor of a boarding platform with minimal horizontal & vertical gaps. This is consistent with the idea of universal design as articulated by Steinfeld [55, 59], yet awareness of this solution may be low, because in the same book, the chapter by Lenker et al [58] only pays lip service to the possibility of level boarding for buses while focusing almost exclusively on existing low-floor bus designs involving ramps. BRT systems have recently started touting level boarding as a feature, not only to allow people with physical disabilities to board independently without necessarily requiring assistance from the driver but to also expedite boarding for all passengers and thereby decrease dwell times at stops. BRT systems in Europe often feature level boarding [71–73], but there are fewer such BRT systems in the US, and US BRT systems' claims to offer level boarding vary much more in validity. Some BRT systems, like services by the Los Angeles Metro, explicitly do not claim to have level boarding and require riders using wheelchairs to use ramps [74]. Some do not claim to have level boarding but phrase things in a way that may confuse riders. For example, the Metro Transit BRT in Minneapolis/Saint Paul claims to have "almost" level boarding but says ramps are required [75], which does not solve problems with ramp failures or provide the same level of independence to riders with physical disabilities. Some do claim to have level boarding, but these claims may be belied by pictures or words. One example is the Everett BRT pilot in Massachusetts which claims to have level boarding even for people in wheelchairs but has pictures of buses with gaps that appear to be too big [76]. Another example is the Flash BRT in Maryland which claims to have level boarding for strollers with "no steps to get on off [*sic*] the bus" but also, with an accompanying picture [77], says the following: "Wheelchairs and scooters should enter through the door at the front of the bus. The driver can quickly deploy a bridge for a smooth entry." Finally, some do feature level boarding, like CTFastrak per the picture in the cited article [78], but may exhibit inconsistent practices, like the Cleveland HealthLine, which in some cases can clearly allow for level boarding [79] but in other cases clearly deviates from proper practices [80]. All of these issues are complicated by public transit agencies making changes to vehicle stock & infrastructure over time, so riders with travel-limiting disabilities who depend on consistency may struggle more. That said, in the near future, horizontal gaps may be minimized more reliably with new automated docking systems [81].

Overall, there is a dearth of rigorous research about the immediate usability of BRT systems in the US for people with various disabilities (not just physical disabilities). Ideally, such research would shed light onto practical problems facing US BRT riders with disabilities and will inform new standards for immediate usability in the creation of new BRT systems & operation of existing BRT systems, especially given that BRT systems are now more frequently chosen over rail rapid transit systems due to lower costs & greater flexibility with vehicles & infrastructure. Necessary research includes but is not limited to understanding how many BRT systems in the US offer true level boarding, how often BRT vehicles in systems with level boarding are misaligned with the platform, how often such misalignments (when they do happen) are solved by deploying a ramp versus realigning, how much time each such solution adds to the total boarding time, how ramp slopes for BRT systems in the US that recommend ramp use compare to those for regular buses or for curb ramps, and how the additional elapsed times compare (from deployment through securement or exit of the passenger through retraction).

Separately, some smaller communities have been able to offer more flexibility to public transit riders. Suen & Sen [26] as well as Rosenbloom [28] have pointed to some services that offer route deviation options on standard public transit, but of those, some only offer these options to elderly people, and others require 24 hours advanced notice (similar to paratransit, as we describe in Sec. VI). These works have also identified some specialized service routes that can replace some fixed-route transit and demand-responsive paratransit services without the need for lengthy advanced reservations. Overall, research and policy developments on these fronts are quite limited. More research is needed to understand the different types of flexible services offered by different types (urban, suburban, or rural) of communities, the issues with immediate usability, cumulative usability, and availability that arise for riders with disabilities in these services, and the financial scalability & sustainability of such services.

VI. PARATRANSIT AND ALTERNATIVE COMMUNITY TRANSIT SERVICES

One may imagine that anyone with a disability would use paratransit services. This view would in principle be especially justified by the ADA requirement that public transit agencies provide paratransit services unless doing so would present a substantial undue burden (which is most pertinent for agencies in smaller communities far from large metropolitan areas) [82]. However, we have shown in Table I that the 2017 NHTS [16] has found that of the 25.5 million people with travel-limiting disabilities in the US, at most 2.9 million used paratransit or similar services at least once ever, of which 2.0 million are not licensed drivers. Thus, although non-drivers with disabilities have are much more likely than drivers with disabilities to use paratransit, just 11% of all people with travel-limiting disabilities have ever used paratransit or similar services, and even this statistic does not account for the frequency of use. Much of the low usage may be explained by constraints on paratransit operations, though we note that the requirements of the ADA & similar laws with respect to paratransit operations means that paratransit is among the few modes in the US with legal standards for availability specifically for people with disabilities.

The principal problem for paratransit operators is cost. Rosenbloom [10] explains that from 1999 to 2011, total paratransit costs across the country grew by 197% in terms of nominal dollars over that period, while inflation in the official US Consumer Price Index (per the US Bureau of Labor Statistics) was approximately 35% [83] over the same period, implying an inflation-adjusted cost increase of 120%, yet paratransit ridership across the country only grew 49% over the same period. Rosenbloom [10, 28] has also shown that paratransit rides cost on average approximately $30 per ride in most urban areas as of 2011, but rider fares are much lower by law (no more than

double the total equivalent public transit fare for the same ride [82]). Rosenbloom [10, 28] has explained that these cost constraints come from the combination of the relatively small number & relatively large geographic dispersal of riders with travel-limiting disabilities who would need paratransit services, making it hard for paratransit providers to efficiently consolidate rides and making the high costs of labor more apparent.

These high costs have led to significant constraints on paratransit operations. First, paratransit agencies have become more stringent over time with respect to qualifying disabilities [10, 26, 28, 84], but studies that acknowledge this do not clearly explain whether this is consistent with the mandates for minimum levels of eligibility set out by the ADA [32, 82]. Rosenbloom [10, 28] has pointed out that while there have been some instances of people with severe disabilities [85] being denied explicitly access to paratransit services, it may be much more common for people with even severe disabilities to not even try to apply for paratransit service eligibility out of discouragement by cumbersome administrative requirements. Thus, a service meant for people with disabilities might fail for subsets of such people that agencies choose to make ineligible. Second, paratransit agencies have limited service areas to people who live within $\frac{3}{4}$ mile of a bus route, and operating hours to the same hours that buses run [10, 28, 82]. Steinfeld & Steinfeld [84] point out that this effectively doubly penalizes riders with disabilities in rural areas, who do not have widespread (or any) public transit coverage to begin with and therefore cannot rely on the law to ensure widespread paratransit coverage to fill the gaps. Third, paratransit services almost always require scheduling rides far in advance [10, 26, 28, 32, 61, 82]. Lubin & Deka [4] have pointed to prior works showing that such restrictive scheduling requirements can hinder the usefulness of paratransit services for getting people with disabilities to jobs, although the survey in that work shows relatively high rates of paratransit use among job seekers with disabilities. These are all failures of availability of paratransit for people with disabilities.

Research about who uses paratransit has been sparse. The study by Bezyak et al [61] was a convenience-based online sample meant to include roughly equal numbers of respondents from different disability subgroups, and it did not use weighting or proportional fitting to make the results representative of the broader population, so it cannot definitively say which subgroups of people with disabilities most often use paratransit. Lubin & Deka [4] have suggested that in the context of job seekers with disabilities in New Jersey, people with cognitive disabilities are less likely to use paratransit services than are people with physical or vision disabilities, but while that work does consider the possibility that people with cognitive disabilities may have difficulties with respect to finding jobs that go beyond transportation problems, it does not directly connect these two ideas. By contrast, Steinfeld [59] claims, from interviews of high-level employees of unnamed paratransit agencies, that most paratransit riders have cognitive disabilities, are morbidly obese, or live in areas where public transit is hard to reach, but has not clarified whether the difficulty of reaching public transit is due to conditions that amplify other physical disabilities as opposed to unavailable pedestrian infrastructure endangering even people without disabilities. Thus, more research is needed to understand the characteristics of paratransit riders. Furthermore, public transit agencies cannot force riders with disabilities who are capable of using public transit to instead use paratransit [82], but it is not clear how many paratransit users could potentially use standard public transit services more regularly if there were improvements to pedestrian infrastructure or other aspects of standard public transit service [28, 59, 61].

Research about problems aboard paratransit vehicles has also been sparse. Simek et al [67], in their convenience-based online surveys of nearly 200 people with vision disabilities, have found that paratransit riders with vision disabilities largely see paratransit drivers as well-trained and trustworthy. However, this does not mean that problems with paratransit drivers are hard to find.

The study by Bezyak et al [61] has shown that nearly 30% of all respondents who have used paratransit services, with a similar fraction of respondents with vision disabilities who have used paratransit services, have reported inappropriate driver attitudes. Remillard et al [86] report, from interviews of older adults across the US, how one participant was injured in a paratransit vehicle from being thrown out of a wheelchair due to the driver failing to secure the wheelchair. Thus, there needs to be more qualitative research to understand the types & depths of problems that people with disabilities face with paratransit drivers, and more quantitative research about the frequencies at which those problems arise.

Returning to aforementioned basic operational problems with paratransit, Rosenbloom [28] has explained, through comprehensive references to paratransit agency data, that costs would balloon if agencies were to expand services to all people with disabilities to even a marginal level, as economies of scale have historically been hard to exploit for paratransit services. Such high costs explain why paratransit agencies often violate legal requirements of availability for people with disabilities, as problems like scheduling inflexibility, delays in pickup, no-shows by paratransit drivers, inflexibility by drivers with respect to riders, overly restrictive eligibility standards & procedures for people with disabilities, and a tendency in practice to discriminate against occasional riders in favor of frequent riders, all violate mandates by the ADA and other relevant laws to provide certain minimal levels of service availability. Quantitatively, Bezyak et al [61] have shown that among all respondents who have used paratransit services, many have reported problems with scheduling (55%), excessive wait times (50%), missed pickup times by the paratransit agency (36%), being kept on the bus for too long (35%), problems with service times (32%), complaints about no-show policies (18%, because while certain no-shows may be the rider's own mistake as opposed to a problem with the paratransit service, riders may lose eligibility after just a few no-shows, which may unduly burden people with more severe disabilities), and losing eligibility (5%, without specifying reasons in further detail). In that work, all of these percentages hold approximately for each specific disability subgroup (vision, hearing, communication, physical, and cognitive), with somewhat higher fractions among those with vision disabilities reporting these problems. However, the survey in that work does not ask about problems with bus lift or ramp failures or other problems of that nature despite having asked about such problems to people with disabilities who ride standard public transit services.

Thus, there needs to be more qualitative & quantitative research about the specific problems faced by people with disabilities who use paratransit services, particularly considering different disabilities, in order to understand the extent to which paratransit services satisfy immediate usability in practice as well as legal requirements of availability for people with disabilities. As the current state of research in this context is so sparse, only with more rigorous research can more specific policy questions be formulated. These questions include but are not limited to understanding the extent to which paratransit riders need more specialized assistance from drivers that might not be available from public transit/taxi/TNC drivers, the extent to which paratransit riders use public transit if pedestrian access to public transit stops were improved, and the extent to which paratransit riders use public transit if the immediate usability as well as cumulative usability of public transit service (including better assurance for people with vision or cognitive disabilities) were improved.

We have discussed in Sec. V how some public transit agencies in small communities have made public transit services operate more like paratransit in terms of being demand-responsive, but these modifications are not exclusive to people with travel-limiting disabilities. Separately, in other small communities, providers other than public agencies are to a large extent responsible for public transit & paratransit for people with travel-limiting disabilities. Some community

transit providers simply provide discounts for taxi rides [26, 28, 32] and contracts or other financial incentives for taxi companies to serve riders using wheelchairs[87]. Furthermore, some demand-responsive community transit services even in larger areas may struggle with costs when considering buying more immediately usable vehicles for riders using wheelchairs that are also small enough to be sustainable in demand-responsive service in car-dependent suburbs (where traditional public transit services are already unsustainable) [88]. Some providers are not primarily in the business of transportation [26, 84], and coordination with local public transit agencies (where those exist) may be hampered by the fact that many community transit services provide assistance for people with disabilities beyond rides themselves [28]. Moreover, some companies, like hotels, that are not primarily in the business of transportation but provide courtesy shuttles have been sued for lack of disability access; progress is hard to assess due to nondisclosure agreements [84]. Some rural communities combine community transit with municipal services like postal service or medical transportation [11, 26]. Finally, volunteer services may be sustained in certain cases by targeted incentive policies [28, 89] but may create an unwanted sense of dependence on the kindness of others [11, 26]. Thus, there is clearly a variety of possible transit service models in smaller communities, including models for demand-responsive or point-to-point services, but there is a dearth of qualitative research about the problems that can arise with these services, and of quantitative research about the frequencies with which these problems arise. These research questions must be addressed before any further policy questions can be formulated, let alone addressed.

We have also discussed in a companion work how municipal governments are forming partnerships between paratransit agencies & TNCs to more effectively provide transportation services to people with travel-limiting disabilities [90] or to people in general whose residential choices & travel patterns do not necessarily conform to prior assumptions by public transit agencies [91]. Three general partnership models prevail. First, some public transit agencies simply provide public transit or paratransit passes for riders to use existing TNC services without modifications, as the MBTA did in a pilot program in Boston for paratransit riders there [90, 92]. Second, public transit agencies may contract with TNCs to provide more specific forms of service through vehicles and drivers provided by the TNC, as is the case with Via in Arlington, Texas [93]. Third, public transit agencies may contractually use TNCs' software platforms to more efficiently route existing public transit or paratransit vehicles & drivers, as is the case with Uber in Marin County, California [94]. These partnerships suggest that Rosenbloom's explanations [10, 28] of the high costs of paratransit as arising from high labor costs and difficulties in consolidating rides can be addressed by TNCs in two main ways. First, TNC software, by design, efficiently & quickly matches riders who could share parts of rides at similar times with minimal delays. Such capabilities could improve the efficiencies and thereby reduce the costs of paratransit services in any partnership model, potentially by retaining fewer drivers through the consolidation of services in certain areas. Additionally, the second and third partnership models listed here could alleviate concerns over the immediate usability of vehicles for riders with disabilities. Second, TNCs have typically paid their drivers less in wages & benefits compared to public transit or paratransit drivers, and have historically spent less money (compared to public transit & paratransit agencies) on training their drivers to address the needs of riders with travel-limiting disabilities, leading to concern that superficial cost savings of these sorts will lead to decreased service quality for riders with travel-limiting disabilities & decreased socioeconomic equity for drivers [95]. Thus, there needs to be more research about the practical pros & cons of different partnership models between paratransit agencies & TNCs for riders with disabilities. These questions include whether public transit & paratransit agencies could use existing large vehicles in conjunction with dynamic routing software to better serve increases in demand induced by the introduction of demand-responsive services and thereby avoid

the aforementioned problems with economies of scale, and whether such partnerships could be leveraged to more effectively train TNC drivers in turn.

VII. INTERSECTION OF WALKING WITH PUBLIC TRANSIT AND PARATRANSIT

We have mentioned in Sec. III and Sec. V that pedestrian infrastructure is critical not only for people with travel-limiting disabilities choosing to walk but also for such people choosing to use public transit services. Here, we explain this further. Lubin & Deka [4] have found in their survey that 50% of respondents were unsatisfied with the safety of pedestrian infrastructure in the context of using public transit to seek jobs, though specific concerns are not stated with greater detail. Furthermore, the number of respondents who are dissatisfied with pedestrian conditions around public transit stops & stations exceeds by 10-15 percentage points the number of respondents who are satisfied. Similarly, Rosenbloom [28] has identified problems that people with disabilities frequently face when using pedestrian infrastructure as part of using public transit services (i.e. buses), including missing or broken sidewalks and has argued that such deficiencies depress public transit use among people with disabilities. Rosenbloom [10, 28] as well as Suen & Sen [26] have also shown that elderly people face similar problems with easily using pedestrian routes to public transit services. Ruvolo [41] has captured similar concerns in a convenience sample survey of over 200 people with disabilities in the San Francisco Bay area, also finding that people with various disabilities would like more street furniture, like benches, in order to make the experience of using public transit more comfortable for them, but does not quote exact numbers of respondents who expressed these concerns (contrary to certain other questions in that survey). Bezyak et al [61] have shown in their study that 26% of respondents report problems with accessible routes to a public transit stop or station, and that work is among the few to show that 25% of respondents report problems with weather in the context of access to public transit, though it is not clear whether "problems with accessible routes" exclusively refers to pedestrian routes, and whether "problems with weather" exclusively refers to walking on the way to a public transit stop or station (as opposed to inclement weather causing problems for public transit operations themselves).

These problems with pedestrian infrastructure, including bad sidewalk quality and paths in front of bus shelters that are too narrow, can lead people with travel-limiting disabilities to choose to drive instead of using public transit, as discussed by Rosenbloom [28] as well as Steinfeld [55]. Furthermore, Rosenbloom [28] explains that paratransit agencies are legally required to serve people with travel-limiting disabilities within the paratransit service area if such people cannot reach regular public transit stops due to lack of pedestrian infrastructure, even if public transit vehicles are immediately usable by such people. This could occur by having paratransit trips entirely replace public transit trips for such people in a point-to-point manner, or by having paratransit services act as feeders taking such riders from their origins to public transit stops and making those riders transfer to public transit services from there. That said, Minot [90] has clarified that paratransit trips that feed into public transit constitute less than 5% of all paratransit trips, and there are significant logistical challenges with coordinating transfers from paratransit services, which must be booked at least 24 hours in advance in most cases and which may arrive significantly later than expected (if a vehicle arrives at all), to public transit services, which operate on fixed schedules. Furthermore, such feeder paratransit services are used by paratransit agencies primarily to save on the greater costs of providing fully point-to-point services where it might be harder to pool a ride with other unrelated riders.

In any case, there needs to be effective coordination between municipal agencies in charge of public transit and those in charge of sidewalk construction & maintenance. Such coordination

would require new legal definitions of immediate usability as well as cumulative usability that explicitly account for the key pedestrian environments leading to and immediately surrounding bus stops or train stations. These policy changes would need to be informed by further research about how walkability for people with disabilities is affected by weather conditions & time of day. Furthermore, as we discussed in Sec. VI and in a companion work, partnerships between paratransit agencies and TNCs could allow paratransit services to pool rides more efficiently, whether for point-to-point services or for feeder services to public transit, so more research is needed regarding the feasibility, costs, operational characteristics, rider experiences, and changes to riders' mobility for such partnerships.

VIII. INTERSECTION OF WALKING WITH MICROMOBILITY SERVICES

In Sec. IV, we have discussed problems with the immediate usability of shared micromobility devices for people with travel-limiting disabilities. However, even people with travel-limiting disabilities who would never use shared micromobility devices can experience problems with travel in the pedestrian context because of such devices, and these problems come in two main flavors.

The first flavor concerns the immediate usability of sidewalks when dockless micromobility devices are left on them. In particular, such carelessness can be hazardous to people in wheelchairs or with low vision using those sidewalks [40, 41, 96]. However, Brown et al [97] have performed observational studies of sidewalks in major urban cores across the US showing that over 25% of observed vehicles, compared to less than 1% of observed micromobility devices, were improperly parked and thereby obstructed the sidewalk, suggesting therefore that perceptions of improperly parked micromobility devices being a big problem for immediate usability of sidewalks may come more from angry unfamiliarity with new small micromobility devices versus apathetic acceptance of improperly parked large vehicles. It remains to be seen if these perceptions, even if colored by cognitive biases, constitute enough of an impetus to widen sidewalks or create new micromobility parking spaces at the expense of road space. That said, some cities are already experimenting with incentives to parking micromobility devices properly, disincentives to parking them carelessly, and new or updated regulations clarifying proper use. Such measures may legally address the problems with immediate usability of sidewalks when blocked by dockless micromobility devices. In any case, there needs to be more research to determine how often this happens and how this correlates with urban form.

The second flavor concerns the new infrastructure that many cities are creating to accommodate micromobility devices (largely referring to bike lanes), even as such cities are simultaneously grappling with how to regulate the docking & use of micromobility devices on sidewalks & roads. There are few peer-reviewed papers systematically studying the impacts (positive or negative) of bike lanes on people with disabilities [98, 99]. Meanwhile, most news articles & op-eds uncritically report qualitative reports biased toward supporting or opposing bike lanes from the perspective of people with disabilities [100, 101]. Local regulations are confusing or contradictory on the issue of whether people in wheelchairs or with other disabilities not on bicycles can use bike lanes [102–104], and local & national design regulations (with very few marginal exceptions mostly by advocacy groups instead of governmental agencies [105–107]) largely pay lip service to accommodating people with disabilities when designing bike lanes but never provide best practices or specifications (especially when compared to regulations for curb ramps) [108–113].

IX. EFFECTS OF CONSOLIDATING OR REPLACING BUS ROUTES

Several public transit agencies in the US have replaced regular bus routes with train lines in order to accommodate greater demand along particular corridors. However, such replacements can negatively affect the mobility of people with disabilities. Lubin & Deka [4] have shown in their study of job seekers with disabilities in New Jersey that while only 12% of respondents do not know how they feel about safety at bus stops or on board buses, this number rises to 26% with respect to being at train stations or on board trains, and that increase comes entirely at the expense of the percentage of people feeling very safe or somewhat safe in such situations. They find similar results for traveling to or from bus stops compared to train stations, particularly as the greater distances between train stations compared to bus stops, especially when a train line largely replaces a bus route, can exacerbate feelings of danger among people with disabilities. This may be tied to the intimate connection between pedestrian infrastructure & public transit use among people with disabilities, which we have discussed in Sec. VII. Rosenbloom [28] cites similar findings to show that replacing bus routes with train lines can depress public transit ridership particularly among people with disabilities.

One may argue that the existence of paratransit options means that any problems that people with disabilities face with public transit need not be addressed directly within those systems, as paratransit can always be depended upon by such riders as a fallback. Indeed, as some transportation planners have shifted away from geographic coverage in bus systems & building expensive rail systems in favor of simpler high-frequency networks of bus service in highly trafficked corridors, particularly in sprawling metropolitan areas like Houston and Dallas [114, 115], it is tempting to think that any gaps in the geographic coverage of bus services can then be filled for people with disabilities by paratransit or other dedicated demand-responsive services. However, Minot [90] as well as Rosenbloom [28] explain that this is not the case. In Sec. VII, we have discussed how paratransit services can act as feeder services for riders within $\frac{3}{4}$ mile of a fixed public transit route if such riders do not have proper pedestrian access to those routes. By contrast, there are no consistent legal provisions at the national level for paratransit services to fill in geographic gaps in bus service beyond $\frac{3}{4}$ mile of a fixed public transit route; in fact, paratransit service areas may shrink further with the consolidation of bus routes, which would doubly penalize people with travel-limiting disabilities who would otherwise depend on paratransit services, but this has not been studied in depth.

Even when bus routes are retained, Lubin & Deka [4] have found in their study, and Rosenbloom [28] has found in citations of prior work, that existing bus frequencies and coverage areas may be insufficient for people with disabilities to get to jobs, given that they often have few other options. Bezyak et al [61] have also reported from their survey that almost 50% of people with disabilities generally report problems with public transit service, though this is not further broken into problems with coverage areas & times versus frequencies & reliability. Thus, while existing regulations may specify minimal standards for availability for people in general through assumptions about walk-sheds for bus stops versus train stations, these may need to be reconsidered specifically through new research & policy actions for people with disabilities and further reconsidered if a proposal to replace a bus route with a train line is ever considered.

X. EFFECTS OF CAR-FREE ZONES

Many cities have gone further than installing bike lanes with respect to promoting active transportation, and the changes made, perhaps most notably the creation of large car-free ur-

ban blocks/areas as well as transit-oriented development, have implications for land use as well. However, such policies for availability and cumulative usability across modes have generally not specifically considered effects for people with disabilities, as legal standards for disability access are typically concerned with immediate usability of specific modes. Furthermore, very few peer-reviewed scholarly works have critically examined the effects of such policies on the immediate usability and cumulative usability of different aspects of the transportation system specifically for people with disabilities, as many transportation professionals have uncritically assumed that such policies would be beneficial for people with disabilities. For instance, Szarata et al [116] briefly mention, with appropriate references, how car-free urban areas can benefit people with disabilities by minimizing points of conflict between pedestrians & drivers and by incentivizing dense development shortening walking distances to key destinations. However, when those authors specifically discuss their study of people's feelings about car-free neighborhoods in Krakow, Poland, they never directly state that any respondents had disabilities. Even though people with physical disabilities have raised concerns about the ways that such car-free blocks can negatively impact the mobility of those who have no alternative to transportation other than door-to-door automobile service [117], most articles (published most often in newspapers, magazines, or blogs, and much less often in academic journals) go no further than briefly mentioning the existence of exceptions to vehicular bans such that those exceptions accommodate drivers or passengers with disabilities or at least do not burden such drivers or passengers beyond what was true of the status quo prior to implementation of car-free policies [118–123]. Steinfeld [59] is among the few who acknowledges these deficiencies, as well as the lack of research about the effects of walkable or transit-oriented development on the mobility of people with disabilities, particularly at different times of day & in different weather conditions. Verlinghieri et al [124] have started to address this in the context of the United Kingdom by interviewing disability advocacy organization representatives there; those representatives have expressed the need for changes in funding, education, and broader cultural attitudes to enable development that favors public and active transportation modes and would therefore benefit many people with disabilities, while acknowledging that private vehicular modes should still be allowed for use by people with disabilities who would not be able to travel in any other way.

XI. DISCUSSION

We have shown in this work that problems that people with disabilities face with active modes & public transportation encompass not only the immediate usability of public transit vehicles but also things like pedestrian infrastructure quality, immediate usability of micromobility devices, topography, and availability and connectivity of the public transit network. Furthermore, problems with some modes have significant effects on the use of other modes, such as a lack of pedestrian infrastructure around bus stops contributing to depressed public transit use, dockless shared micromobility devices blocking sidewalks discouraging walking trips, or car-free zones in urban cores. These problems with cumulative usability impede tripmaking by people with physical disabilities, and some of these newer developments have not been studied much in academic or policy contexts. These challenges raise questions relevant to basic research about the travel habits of people with travel-limiting disabilities, which we list below.

- How often do people with disabilities encounter broken, blocked, or otherwise dangerous pedestrian infrastructure?

- How do raised crosswalks affect the reality & perceptions of safety for pedestrians with disabilities, and how does this affect tripmaking patterns for such people?
- How easy might it be for people without disabilities or for people with different disabilities to use micromobility devices that are adapted for use by people with disabilities?
- How often do people with disabilities encounter sidewalks blocked specifically by micromobility devices, and how does this vary by urban form, time of day, and time of year?
- How often do people with disabilities come into conflict or collide with bicyclists when crossing bike lanes, and how does this vary by urban form, time of day, and time of year?
- How are tripmaking patterns and overall place-based accessibility for people with disabilities affected in either direction in urban areas where certain blocks ban the use of automobiles?
- What are the problems that people with disabilities face with fare payment systems & fare gates for buses as well as for trains, how often do those systems fail, and what are the best practices for future design?
- How are assumptions about walk-sheds for bus stops & train stations affected by the confluence of disability, topography, and weather conditions?
- How often do elevators in train stations fail?
- How do bus ramp slopes in BRT systems in the US that use ramps compare to those for traditional buses?
- How do people in wheelchairs emotionally feel when facing forward versus backward on a public transit bus with respect to different safety designs, and what are best practices for such designs to minimize the feeling of being singled out?
- What are the disability characteristics of people who use paratransit services?

Challenges with active mobility & public transportation also raise questions relevant to policy-making and interpretation of existing policies, which we list below.

- Do the ADA & other relevant disability laws require more effort to be made to provide safe & minimally obstructed sidewalks, crossings, and bicycle paths particularly near where people with disabilities may live or travel, or must new laws be passed to fill those gaps? Furthermore, do the ADA & other relevant disability laws require new standards for bike lane designs to facilitate safe crossing by people with disabilities when walking or when boarding/deboarding a vehicle?
- How should the ADA & other relevant disability laws be interpreted, or should other laws be passed, with respect to the use of wheelchairs & medical scooters in bike lanes?
- Do standards for curb ramps need to be revised in light of problems demonstrated for people in manual wheelchairs using typical bus ramps?
- Do the ADA & other relevant disability laws require municipal transit agencies to simplify fare structures to accommodate people with cognitive disabilities, and if so, how should such simplification be done?

- How may public transit agencies & public works agencies in metropolitan areas better coordinate the construction & maintenance of immediately usable pedestrian infrastructure around bus stops (and train stations if applicable)?
- Do the ADA & other relevant disability laws require public transit agencies to guarantee a minimum level of immediate usability for people with disabilities to use pedestrian infrastructure around bus stops or train stations, or are new laws needed?
- Do public transit agencies legally need to reassess assumptions about walk-sheds for bus stops if they are affected by the confluence of disability, topography, and weather conditions, and if so, how should they do so?
- Do public transit agencies legally need to reconsider assumptions about walk-sheds for bus stops versus train stations given the effects of replacing a bus route with closely-spaced stops with a train line with farther-spaced stations?
- In larger metropolitan areas with train systems, how might public transit agencies more effectively raise money to improve immediate usability of stations that currently violate legal standards for people with mobility disabilities (for example, due to lack of elevators)?
- How might metropolitan areas & larger regions create legal standards for immediate usability of BRT systems and for ensuring that any failures therein do not disproportionately harm people with disabilities?
- How do increasing restrictions on eligibility for paratransit jibe with mandates by the ADA & related laws?
- How might the ADA, related laws, or new laws address the lack of paratransit service in communities that do not have regular public transit services?
- How might policies improving immediate usability and cumulative usability of public transit, including but not limited to better pedestrian infrastructure and better vehicle design, affect paratransit ridership?
- How might different rural or sparse suburban communities combine demand-responsive point-to-point public transit services with other municipal services effectively?
- Are micromobility companies bound by existing disability laws to provide adapted micromobility devices, and in any case, how financially sustainable is it to expect such companies to provide such devices without further support? Could micromobility devices be designed for adaptations to be installed & removed easily in a modular way, analogous to how some carsharing companies provide adapted vehicles [50, 125]?

The above questions of research & policy have focused on the problems that people with disabilities may face with public transit, paratransit, or active transportation modes, whether in isolation or in conjunction with each other. However, there are overlaps in characteristics of these modes with private vehicular modes, and people with disabilities do not uniformly consider only active or public transportation modes to the exclusion of private vehicular modes. Therefore, we consider broader research questions that are applicable to all of these modes, whether individually or in concert.

- How are tripmaking patterns and overall place-based accessibility for people with disabilities affected by different topographies and weather conditions?

- How often do ramps & lifts in public transit buses, trains, paratransit buses, taxis, and TNC vehicles fail, how often do they require manual deployment, and how often do such vehicles with broken ramps or lifts stay in operation before being taken out of service?

- What is the distribution of times elapsed for people using wheelchairs to board and be safely seated/positioned in a traditional bus, BRT vehicle, train, paratransit vehicle, taxi, or TNC vehicle?

- What is the reliability of flip-out versus slide-out bus ramps, and how are they typically operated when automatic operation fails?

- How many BRT systems in the US actually feature level boarding, how often do misalignments of the vehicle with the platform occur, how often are such misalignments solved by realignment versus using a ramp? Furthermore, how many other vehicular modes feature level boarding?

- How often do individuals with disabilities face discrimination aboard buses, trains, taxis, and TNC vehicles, or denial of service or bad treatment by drivers of those vehicles, and how do these statistics vary with respect to different disabilities & their severity?

Beyond basic research questions, there also exist policy questions that affect active and public transportation modes alongside private vehicular modes. Some of these policy questions are applicable to each mode individually, while others make the most sense for coordination among different modes. The latter point will be especially important when considering improvements to the broader transportation system as a whole for people with disabilities.

- Do the ADA & other relevant disability laws need to account for the ways that cumulative usability for people with disabilities may be affected by different topographies and weather conditions?

- What policies may promote greater training of TNC drivers, public transit & paratransit drivers, and taxi drivers to accommodate the personal physical & emotional needs of elderly riders or other riders with disabilities, and to minimize conflicts among such drivers, riders with disabilities, and (especially in public transit buses) riders without disabilities?

- What policies could incentivize the integration of TNC software platforms into the operations of taxi companies & paratransit agencies?

- What are the best practices for partnerships among public transit & paratransit agencies, taxi companies, and TNCs to provide services with vehicles immediately usable by people with disabilities?

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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 ridehail 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", and "micromobility spontaneity", 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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