Age-Inclusive Design Framework for On-Demand, Shared Autonomous Vehicles

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Abstract

The often repeated promise of autonomous vehicles is to make transportation safer, cleaner, more accessible, and convenient - in particular for vulnerable and underserved groups, such as older adults and people using mobility devices. This future, however, is far from guaranteed; rather, it must be paved by a number of stakeholders, including at minimum, first those who have been traditionally underserved, as well as designers, AV makers and operators, policy makers and regulatory authorities. If we do not carefully study the mobility needs of users – young and old – and design to meet them, we stand to repeat the same fate of in-accessibility in new mobility as in the case of transportation network companies (TNCs). The time to think about age-inclusive design is now for AVs, and I make a case for this here. This thesis explores the following questions: 'How can we imagine a fully autonomous future if we do not have a viable transportation pathway for younger children and older adults?' 'What challenges might users of mobility devices (e.g., rollators, baby strollers) face in using driverless vehicles with hitherto unseen form factors?' 'What spatial allowances and features should vehicle designers consider when re-imagining the interior space of autonomous vehicles?' The study analyses user needs, questions, and suggestions across ten (10) vehicle touchpoints, and presents a series of recommendations aimed for design, operation, policy, regulation, and institutional reform.

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1. Chapter One – Introduction

Background

Aging Demographics

The UN predicts that by 2050, there will be more people over the age of 60 than adolescents and youths between ages 10 to 24 for the first time in global history.[1] This 'demographic transition' has wide implications for who regional planners serve in shaping the built environment and for whom cities and towns plan transportation services.

As people have fewer children and better access to healthcare, the phenomenon of aging becomes increasingly more pronounced. This shift, however, is not limited to urban centers. On the contrary, studies show that the majority of older adults settle in suburban or rural areas - for a variety of reasons, including rising real estate prices in city centers. [2]

In the North American context, these neighborhoods are characterized by sprawl and a heavy reliance on automobility for essential and leisure travel. Even as urban planners tend to advocate for 15-minute neighborhoods, agglomeration, and champion public transit over cars, many American seniors will continue to live in geographies with poor transit connectivity.[3]

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[1] United Nations, Department of Economic and Social Affairs, and Population Division. World Population Ageing, 2017 Highlights, 2017.

[2] "More Older Adults Are Living in Lower-Density Neighborhoods | Joint Center for Housing Studies." Accessed May 5, 2022. https://www.jchs.harvard.edu/blog/more-older-adults-are-living-in-lower-density-neighborhoods.

[3] It is worth noting here that driverless services will likely not alleviate personal car dependence in the short term since limited rollout of AVs begin first in suitable test areas (e.g., deserts), then move to metropolitan cities. It may be some time before services become ubiquitous in suburban areas.

Personal Automobile Dependence in the United States

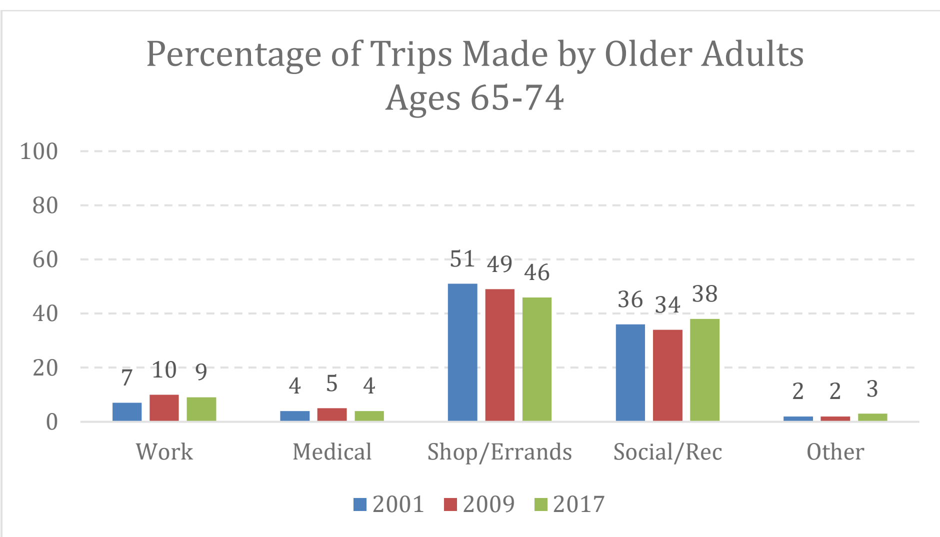
Based on the latest National Household Travel Survey by the Federal Highway Administration (2017), 'driving' or 'being driven' accounted for 86% of travel of those between ages 65-74, and 87% for those 75 and over, while transit accounted for 1%.[4]

Percentage of seniors travel by mode across NHTSA years[5]

Travel Mode	Ages 65-74			Ages 75+		
	2001	2009	2017	2001	2009	2017
Walk	8%	9%	10%	9%	9%	10%
Bike	0%	1%	1%	0%	0%	0%
Driver	69%	69%	68%	61%	62%	62%
Passenger	21%	18%	18%	27%	25%	25%
Transit	1%	2%	1%	2%	1%	1%
All other modes	1%	1%	2%	1%	3%	2%

Table 1 – How older adults travel by transportation mode (NHTSA)

We also know that across these survey years (2001, 2009, 2017), shopping/ errands or social/ recreational travel was the most prevalent compared to other categories (work, medical, other).



[6]

[4] FHWA NHTS Report: Travel Trends for Teens and Seniors. February 2019. Accessed February 21, 2023. https://nhts.ornl.gov/publications
[5] Ibid.
[6] Ibid.

Table 2 - Percentage of Trips Made by Older Adults Ages 65-74

This behavioral data should inform how businesses and policies are designed when aiming to support older adults with mobility needs. Designing mobility solutions aimed solely at enabling medical trips, for example, would run contrary to the regular needs and desires of older population segments.

Why Not Keep with the Status Quo?

Even if the majority of trips made by older adults in the U.S. are by Private Motor Vehicles (PMVs), there is real cause to envision alternative futures. Here is an illustrative and non-exhaustive list of reasons:

1. **Safety risk** - The act of driving may become more dangerous over time, particularly in later years of life.
2. **Parting with the keys** - One may become unable or significantly restricted in driving at a certain stage.
3. **Environmental factors** - There are also reasons external to the driving agent, such as one's negative contribution to climate change, air pollution and air quality, and traffic congestion.

Environmental Factors

The environmental impact of automobiles is well documented in the urban planning field and beyond. Transportation is the largest category of greenhouse gas (GHG) emission (27%), and light-duty vehicles (including passenger cars) is the largest of those (57%).[7] Going beyond simply emission, however, cars are inimical to the environment

[7] Fast Facts on Transportation Greenhouse Gas Emissions | US EPA. (2022, July 14). US EPA. https://www.epa.gov/greenvehicles/fast-facts-transportation-greenhouse-gas-emissions

for several reasons. There is the embodied carbon in the pre-assembly production of steel, rubber, glass, plastic, paints, as well as post-life waste.[8] And the ever-expanding construction of roads and highways also means eroding green lands. Looking beyond environmental risks, driving also poses risks to human safety.

Safety Risk

According to a RAND policy paper by David S. Loughran and others, older adults (65+) are 573% more likely than adults ages 24-54 to be killed in a car accident, even though they are only slightly more prone to cause accidents (16% than more those ages 24-54 compared to younger adults ages 15-23 who are 188% more prone to cause accidents than their 24-54 counterparts).[9] The authors of the study conclude that "The main danger that they pose on the road is not to others but to themselves."[10]

Parting with the Keys

According to the same study, on average as people age, there are bodily changes that can make driving more difficult. The most common of these is a decline in eyesight: "Glaucoma, macular degeneration, and cataracts—all of which become more common with age—reduce night and peripheral vision and vision acuity and cause individuals to become more sensitive to glare."[11] Reflexes and reaction times can often slow down and the ability to "take in information from disparate sources simultaneously" may be reduced.[12] The increased propensity to suffer from diseases with sudden symptoms, such as heart disease or stroke, can also contribute to road accidents.

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[8] National Geographic Staff. (2021, May 3). The environmental impacts of cars, explained. Environment. https://www.nationalgeographic.com/environment/article/environmental-impact?loggedin=true&rnd=1681945130180

[9] David S. Loughran, S.A. Seabury, L. Zakaras. "Regulating Older Drivers: Are New Policies Needed?" RAND Corporation. 2007. https://www.rand.org/content/dam/rand/pubs/occasional_papers/2007/RAND_OP189.pdf

[10] Ibid.

[11] Ibid.

[12] Ibid.

This is not to say that all older drivers will have diminishing driving abilities or need to give up driving at some stage. On the contrary, a recent report by the Institute of Transportation Studies at UCLA shows older Americans are driving more than previous generations of older adults – i.e., more miles as well as driving later into life.[13]

Even still, knowing some of the safety risks that increase with age, older drivers tend to self-regulate their driving parameters (e.g., avoiding highways, certain maneuvers, or driving at night) when compared to younger cohorts and sometimes cease to drive all together.[14] What happens when those who depend on PMVs for almost the entirety of their transportation needs one day cannot get behind the wheel?

Quality of Life Impact from Ceasing to Drive

The subsequent decline in the quality of life can be precipitous in some cases. Studies have shown links between driving cessation and a decreased level of out-of-home activities[15], a reduced network of friends[16], depression[17], and a more accelerated decline

[13] Wachs, Martin, Evelyn A. Blumenberg, Andrew Schouten, and Hannah R. King. "Transportation, Quality of Life, and Older Adults," April 1, 2021. https://doi.org/10.17610/T6T30J.
[14] Ibid.
[15] Marottoli, R. A., de Leon, C. F. M., Glass, T. A., Williams, C. S., Cooney, L. M., & Berkman, L. F. (2000). Consequences of Driving Cessation. Decreased Out-of-Home Activity Levels. The Journals of Gerontology: Series B, 55(6), S334–S340. https://doi.org/10.1093/geronb/55.6.S334
[16] Mezuk, B., & Rebok, G. W. (2008). Social Integration and Social Support Among Older Adults Following Driving Cessation. The Journals of Gerontology: Series B, 63(5), S298–S303. https://doi.org/10.1093/geronb/63.5.S298
[17] Fonda, S. J., Wallace, R. B., & Herzog, A. R. (2001). Changes in Driving Patterns and Worsening Depressive Symptoms Among Older Adults. The Journals of Gerontology: Series B, 56(6), S343–S351. https://doi.org/10.1093/geronb/56.6.S343;
Marottoli, R. A., Leon, C. F. M. de, Glass, T. A., Williams, C. S., Cooney, L. M., Berkman, L. F., & Tinetti, M. E. (1997). Driving Cessation and Increased Depressive Symptoms: Prospective Evidence from the New Haven EPESE. Journal of the American Geriatrics Society, 45(2), 202–206. https://doi.org/10.1111/j.1532-5415.

in health.[18] [19] Against these challenges, autonomous vehicles hold the inherent potential to alleviate these issues while maintaining comparable levels of mobility as with PMVs:

Problems with the Personal Auto-Centric Status Quo	Characteristics of AVs	Risk Mitigation by AV
Safety risk or insecurity posed when driving in older age or with mobility impairment(s)	Human driving skills, acuity, and attentiveness are not required	Collision by human error reduced
Curtailed freedom of mobility when ceasing to drive (or not driving)	Human driving skills and license not required for travel	Freedom of movement maintained
Negative contribution to congestion, climate, and air quality from the act of driving	Majority of mass market L4 AVs are also EVs as well as being designed and marketed as on-demand shared fleets	Adverse environmental impact reduced

Table 3 – Characteristics of Autonomous Vehicles

Another Group that will be riders of AVs: Children

Besides older adults, there is another age group my study will pay close attention to – and that is minors (and in particular children under the age of independent travel) that rely on rides in personal motor vehicles (PMVs). Even as birth rates decline in the United States since the post-war period, the number of children has not, and there were roughly 48 million children between age 0 – 11 and roughly 73 million between ages 0

[18] Edwards, J. D., Lunsman, M., Perkins, M., Rebok, G. W., & Roth, D. L. (2009). Driving Cessation and Health Trajectories in Older Adults. The Journals of Gerontology: Series A, 64A(12), 1290–1295. https://doi.org/10.1093/gerona/glp114.

[19] Note that this is not the only line of conclusion that health researchers have drawn. It is worth noting that driving cessation under certain conditions also reduces crash risks, which is positive. Other more recent studies show that quality of life outcomes after driving cessation are more complex and that certain subgroups even have improved outcomes under certain conditions.
Bennetts, R., & Taylor, J. E. (2021). Health and Quality of Life Outcomes of Driving Cessation for Older People are More Complex Than We Thought. Clinical Gerontologist, 45(4), 821–832. https://doi.org/10.1080/07317115.2021.1978122.

– 17 in 2021. That represented around one fifth (20%) of the U.S. population.[20] If we add the parents/ caretakers that accompany them, this is an even larger group that AV makers need to design for and ensure not to neglect.

The (Highly Contingent) Promise of Autonomous Vehicles

Autonomous vehicles have the potential to make transportation safer, more convenient, and enjoyable for older adults, caregiving parents and children. This future, however, is not a given, and can only be ensured by understanding the travel needs, behaviors, and consumer patterns of older adults and parents, and by creating products and user environments that are age-inclusive.

It is reported that between 19 to 24 percent of older adults travel with mobility aids or devices, such as rollators, walkers, canes, crutches, wheelchairs, power scooters.[21] Infants and children similarly need mobility devices, such as strollers, boosters, car seats and the like. Even as AV makers think through making their vehicles more wheelchair accessible - which has over time become nearly synonymous with vehicle accessibility – it is unclear whether AVs are being designed with mobility devices commonly used by parents with children and older adults in mind.

One narrative I heard repeated across several AV makers was 'We are focused heavily on getting the technology to work at this stage. Once we have worked through these

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[20] POP1 Child population: Number of children (in millions) ages 0–17 in the United States by age, 1950–2021 and projected 2022–2050. (n.d.). https://www.childstats.gov/americaschildren/tables/pop1.asp

[21] Fraade-Blanar, L. (2022, June 3). Transportation Equity for Older Adults. RAND. https://www.rand.org/pubs/perspectives/PEA1615-1.html.
Gell, Nancy M., Robert B. Wallace, Andrea Z. LaCroix, Tracy M. Mroz, and Kushang V. Patel. "Mobility Device Use Among Older Adults and Incidence of Falls and Worry About Falling: Findings From the 2011–2012 National Health and Aging Trends Study." Journal of the American Geriatrics Society 63, no. 5 (May 2015): 853–59. https://doi.org/10.1111/jgs.13393.

priorities, we will be able to improve features for edge users.' For those who have seen the rise of the Transportation Network Companies (e.g., Uber, Lyft) over the last decade, we have heard this sort of promise before, but cannot be surprised at its under-delivery. The time to think about age-inclusive design is now for AVs, and I lay out a case for urgency in the scoping section below. A central question that motivates the study is 'how can we ever imagine a fully autonomous future if we do not have a viable automated transportation pathway for younger children and older adults?'

Study Scope

This study zeroes in on the <u>spatial needs and interior design considerations for on-demand shared format level 4 and 5 autonomous vehicles</u> in servicing an ever-growing segment of our population, older adults - and in particular those who use mobility aids and devices - as well as touching upon the needs of parents traveling with babies or children, and airport travelers with wheeled carry-on baggage.

1.1.1 Study Scope: Terms and Definitions

A level of precision is required in describing what we mean by the "spatial needs and interior design considerations for on-demand shared level 4 autonomous vehicles," as well as why particular focus is put on these types of future vehicles.

Given the time constraint of this study and in order to zoom in with a certain level of granularity. For this particular study, I focus on the **<u>interior</u>** environment of the vehicle and largely bracket aside the built environment/roadways, and the vehicle exterior. The reason for this is threefold:

1. To provide granular discussion on age-inclusive AV interior considerations in a way that other high-level AV studies have not yet done given their breadth of scope,
2. Stemming from an acknowledgement that the built environment in many ways is even more critical to usability and accessibility than the vehicle, and therefore deserves its own deep dive. Moreover, it is typically more useful to this analysis in a way that is specific to particular built and natural contexts (e.g., taking into consideration varying topologies, climate, density, permitted modes, pedestrian activity/patterns, demographics, regulations, and other environmental factors from place to place),
3. Owing to study time constraints, and therefore a deliberate choice to examine the usability of vehicle prototypes for particular segments of our population as the prototypes go through further iteration, testing, and feature refinement.

1.1.2 Scope Illustrations

Vehicle Interior Built Environment + Vehicle Exterior/ Mechanics

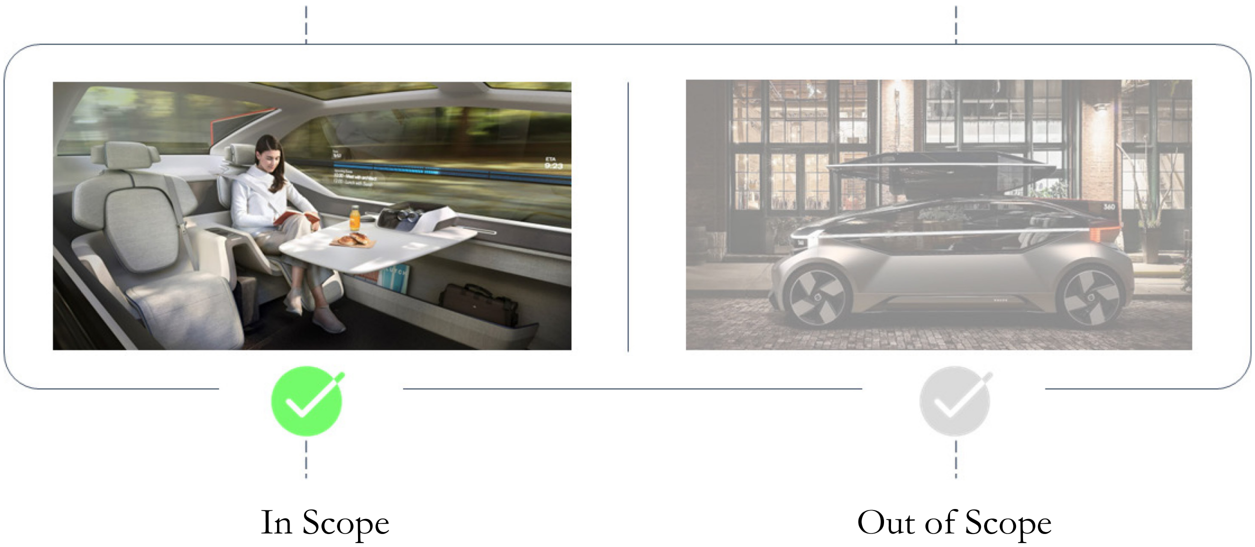

Figure 1 – Scope Illustration I (Photo credit: Volvo)

<u>On-demand</u> and **<u>Shared</u>** formats are distinguished from private motor vehicles (PMVs), which are individually owned and operated (e.g., Tesla automobiles) as well as from fixed route public transit (PT) vehicles (e.g., buses). The reason for these distinctions is threefold:

1. A shared or share-able AV creates a specific type of interior layout - one that will typically prioritize seating space for the riders as well as their safety, provide some buffer space between the riders for rides as well as entering and exiting while others are seated. This is in contrast to PMVs that may also have trunk/ compartmented storage space and additional comfort-related and infotainment amenities.
2. Moreover, space management for PMVs vs. on-demand, shared vehicle is very different. For one, one is able to leave possessions and attachments (car seat bases) in PMVs for subsequent rides whereas one cannot for the latter vehicle type. Next, PMV space is much more individually controlled than for shared vehicles.

3. Finally, on average, fixed-route public transit vehicles are more strictly regulated on accessibility by the different levels of government than for ride-hailing/TNC entities. This means that recommendations and policy instruments used for each will differ.

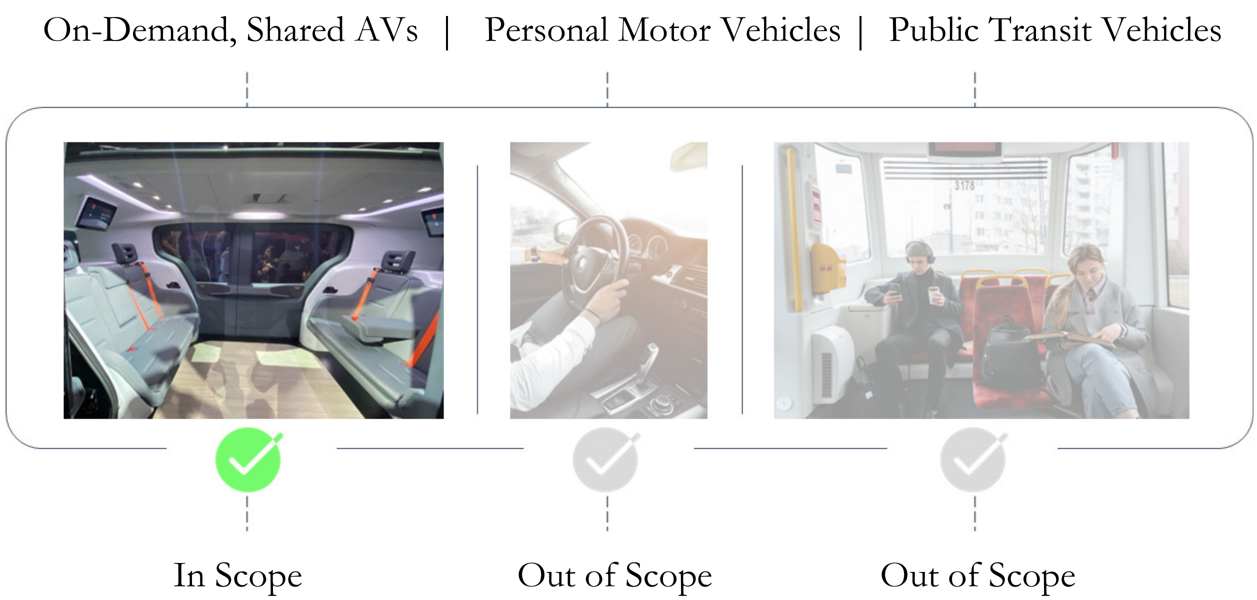

Figure 2 – Scope Illustration II
Photo credits: left to right - Cruise, Creative Commons - Hassan Ouajbir, Mart Production

Lastly on scope, what are **<u>Level 4, 5 vehicles</u>**? L4 and L5 denote levels of "high automation" and "full automation" respectively, defined by the standard setting body SAE.[22] This distinction is important, as there has been much public confusion fueled by the media and auto manufacturers like Tesla to describe lower states of driving automation as 'autonomous.'[23] For simplicity, Level 0 to 3 helps the human operator drive safer; L4 and L5 is meant to be machine operated with high to full automation - with the key difference being that L4 limits the operational design domain (e.g., to

[22] SAE Levels of Driving Automation Refined for Clarity and International Audience. https://www.sae.org/blog/sae-j3016-update
[23] Ohnsman, A. (2023, January 4). Tesla Calling Its Cars 'Full Self-Driving' May Run Afoul Of New California Law. Forbes. https://www.forbes.com/sites/alanohnsman/2023/01/04/tesla-calling-its-cars-full-self-driving-may-run-afoul-of-new-california-law/?sh=4c716f11e2f3.

certain geofenced areas, weather conditions, times of day, etc.) whereas L5 is autonomy under any and all conditions.[24] See diagram below.

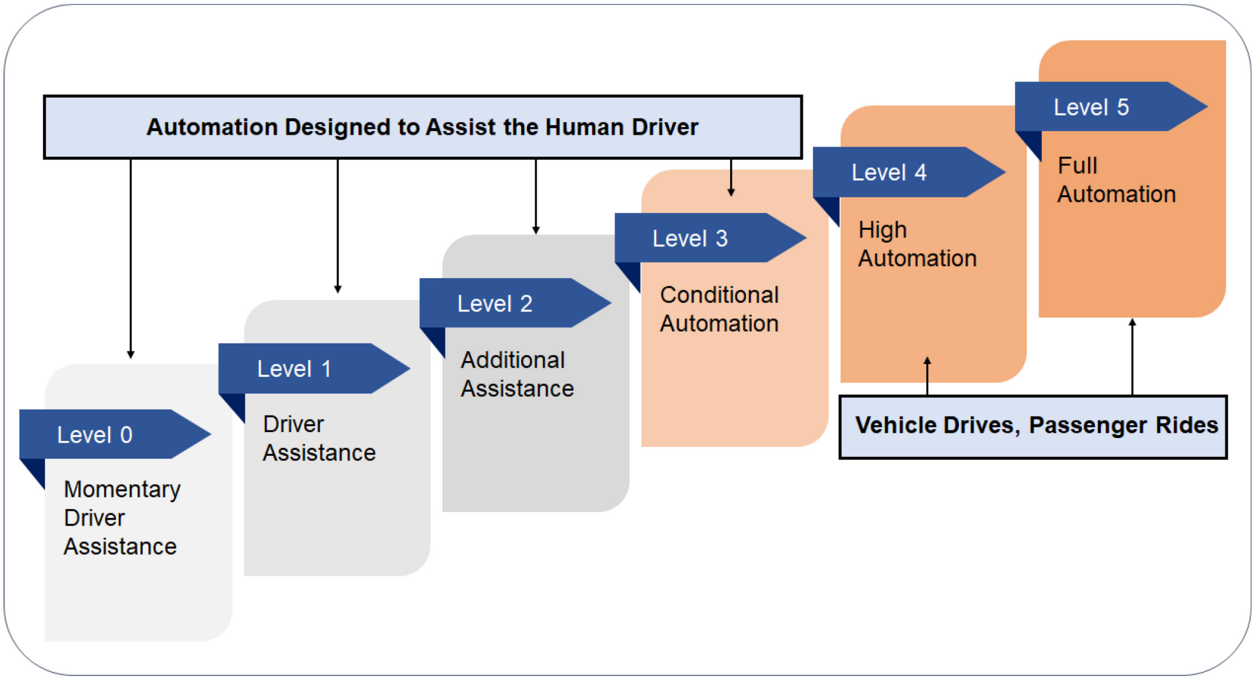

Figure 3 – Levels of Driving Automation

Credit: Diagram created by David Hong, 2023. Content comes from the NHTSA and SAE.

In contrast to PMVs with Advanced Driver Assistance System (ADAS) features, which fall into Level 2, high and fully automated vehicles do not require manual driver intervention. The National Highway Traffic Safety Administration (NHTSA) describes an L4 state as "When engaged, (the) system drives, you ride,"[25] and for L4 and above, vehicle form factors are able to evolve by removing driver seats and controls. For a concise description of all 6 levels of driving automation, visit the NHTSA Automated

[24] Automated Vehicles for Safety | NHTSA. https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety.
[25] Ibid.

Vehicles page.[26] For a slightly more descriptive explanation, visit Aptiv's Mobility Insider page.[27]

By removing the driver, and allowing for a passenger-only vehicle, this also has a range of implications for users who hitherto may have depended on human beings for certain mobility-related activities (e.g., asking to be dropped off somewhere with greater precision, split second changes, asking for seating adjustment, troubleshooting a door or window malfunction, asking for help or assistance during entry, exit, or mid-ride, etc.). According to the 2021 AARP report, "new mobility companies focus on the curb-to-curb experience, but many in this (older) population require door-to-door or hand-to-hand service."[28]

1.1.3 Study Scope: Why Focus on L4 and L5 Vehicle Interiors?

As previous studies have pointed out, there are many individual elements that must come together in order to make this form of transportation accessible, but more importantly, make it a convenient, attractive and a practical travel option to adopt. Solving for the vehicle interior alone will not accomplish this. Nevertheless, it is the author's belief that this is an underexplored yet critically important part of the equation and pathway to an age-inclusive AV future. There are at three reasons why I focus on the vehicle:

[26] Automated Vehicles for Safety | NHTSA. https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety.
[27] What Are the Levels of Automated Driving? (November 5, 2020). Aptiv. https://www.aptiv.com/en/insights/article/what-are-the-levels-of-automated-driving
[28] Fraade-Blanar, Laura, Nico Larco, Ryan Best, Tiffany Swift, Marjory S. Blumenthal, and AARP Public Policy Institute. "Older Adults, New Mobility, and Automated Vehicles." Washington, DC: AARP Public Policy Institute, February 17, 2021. https://doi.org/10.26419/ppi.00132.001.

1. **Development cycles** - New high automation (commonly referred to as Level 4 or L4 vehicles) designs have been prototyped for several years by the major AV makers and do not yet adequately exhibit features and designs that many older adults express they would need to board, exit, and ride comfortably. Vehicle R&D, design cycles are long and modification typically becomes more costly in production and greatly more expensive in mass production. To believe that we can get it right starting on the next iteration is wishful thinking. On average, the lifespan of cars is getting longer (~12 years in 2020 - the highest it has ever been)[29], and the CEO of one of the leading AV makers estimates their new vehicle to be able to service 1 million miles in urban settings. That would be approximately 3-4 times the lifecycle length of today's leading vehicles with lifespans between 240,000 - 290,000 miles.[30] It is arguably important to get accessibility and usability right from the start, and ideally even better in subsequent iterations.

2. **Bad on-demand precedents** - Look at Uber and Lyft. These 'transportation network companies (TNCs) have pushed accessibility and inclusivity largely to the wayside and operate without significant consequence. In 2022, a San Francisco court ruled that not offering wheelchair-accessible vehicles (WAVs) did not violate ADA.[31] Furthermore, TNCs do not need to offer accessibility accommodations in every market, and allow for practices that in effect discriminate against riders with disabilities. In 2021, the U.S. District Court for the Northern District of California

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[29] Colias, M. (2021, June 14). Americans Are Keeping Their Cars Longer, as Vehicle Age Hits 12 Years. WSJ. https://www.wsj.com/articles/average-u-s-vehicle-age-hits-record-12-years-11623680640.
[30] Dickler, J. (2022, December 5). These 10 cars have the greatest potential lifespan — and 6 are Toyotas. CNBC. https://www.cnbc.com/2022/12/04/these-10-cars-have-the-greatest-potential-lifespan.html.
[31] Domenech, A (2022, July 28). Uber doesn't have to offer wheelchair-accessible rides in every market, judge rules. https://thehill.com/changing-america/respect/equality/3578440-uber-doesnt- have-to-offer-wheelchair-accessible-rides-in-every-market-judge-rules/.

found that Uber was charging waiting fees to users in wheelchairs and power scooters.[32]

In the on-demand vehicle transportation market, there is little if any self-regulation of behavior with regards to accessible inclusivity, and it is painfully difficult to bring greater accountability once in full operation. Key times to course-correct are during permitting and incremental expansion approvals.

What sets a few US AV makers apart from traditional TNCs is that – at least two AV makers vertically own both the vehicle design and manufacturing as well as the fleet operation. This is in contrast with TNCs who provide only the platform but do not have complete control over their fleet or their drivers. Because there is no driver or separate vehicle owner, the accessible design and operation of the vehicle is that much more important in the AV story.

3. **Vehicles vs. built environment** - Even though the built environment is critically important for accessibility - particularly for many older adults who encounter barriers in the first and last miles and few feet of their journeys - vehicles are still significantly more malleable than the rigid built environment. In fact, most AV makers design and plan with the assumption that the built environment will largely remain the same (with minor exceptions).[33] Therefore, while work is required on

[32] Justice Department Sues Uber for Overcharging People with Disabilities. (2021, November 10). OPA | Department of Justice. https://www.justice.gov/opa/pr/justice-department-sues-uber-overcharging-people-disabilities.

[33] States and municipalities that are actively partnering with AV companies to augment their micro-transit networks, extend transportation coverage, introduce new services, or upgrade their infrastructure can be found. There are also projects like the planned road network in Michigan for connected and automated vehicles commissioned by Cavnue (an Alphabet company).
Secures $130 Million to Build the World's Most Advanced Road Network for Connected and Automated Vehicles. (2022, April 27). Cavnue. https://www.cavnue.com/news/cavnue-secures-130-million-series-a-project-moves-forward-in-michigan/.

both fronts to make AV rides more accessible, the vehicle is where more changes can be made in the prototyping phases.

4. **Regulatory potential** - Because AVs are relatively new and still require federal, state, and local approvals, there is potentially room for additional regulation. Furthermore, the operational landscape presently is relatively neat with three (3) DMV deployment permit holders in the State of California (Cruise, Nuro, Waymo) – of which only 2 are passenger serving.[34] However, as of April 2023, there are more than forty (40) permit holders for AV testing – either with a driver or without a driver. There is testing in other states, and the need to govern and standardize rules and norms at an interstate level is as important in the medium run as it is at a state and substate level.

Below is an illustration of important factors for a more age-inclusive AV design. The list is non-exhaustive, but illustrates some of the elements that can contribute to positive or negative rider experiences. As mentioned, this study focuses primarily on the vehicle design pillar and more specifically the interior design and spatial allowance aspects based on qualitative interviews. Given the time and resource constraints of the study, other elements are tabled aside for future study. The **purple box** shows our **focus area** and scope.

As a final note on scope, my emphasis and analysis on wheelchair and power scooter users may be shallower than other comparable studies in this field. While their users and these devices also require careful study, this project has honed in on mobility aids, user voices, and experiences that are largely missing from AV-related literature.

[34] State of California Department of Motor Vehicles. (2023, April 12). Autonomous Vehicle Testing Permit Holders - California DMV. California DMV. https://www.dmv.ca.gov/portal/vehicle-industry-services/autonomous-vehicles/autonomous-vehicle-testing-permit-holders/

Clarifying the Focus of this Study – as marked inside the purple box (Vehicle Design)

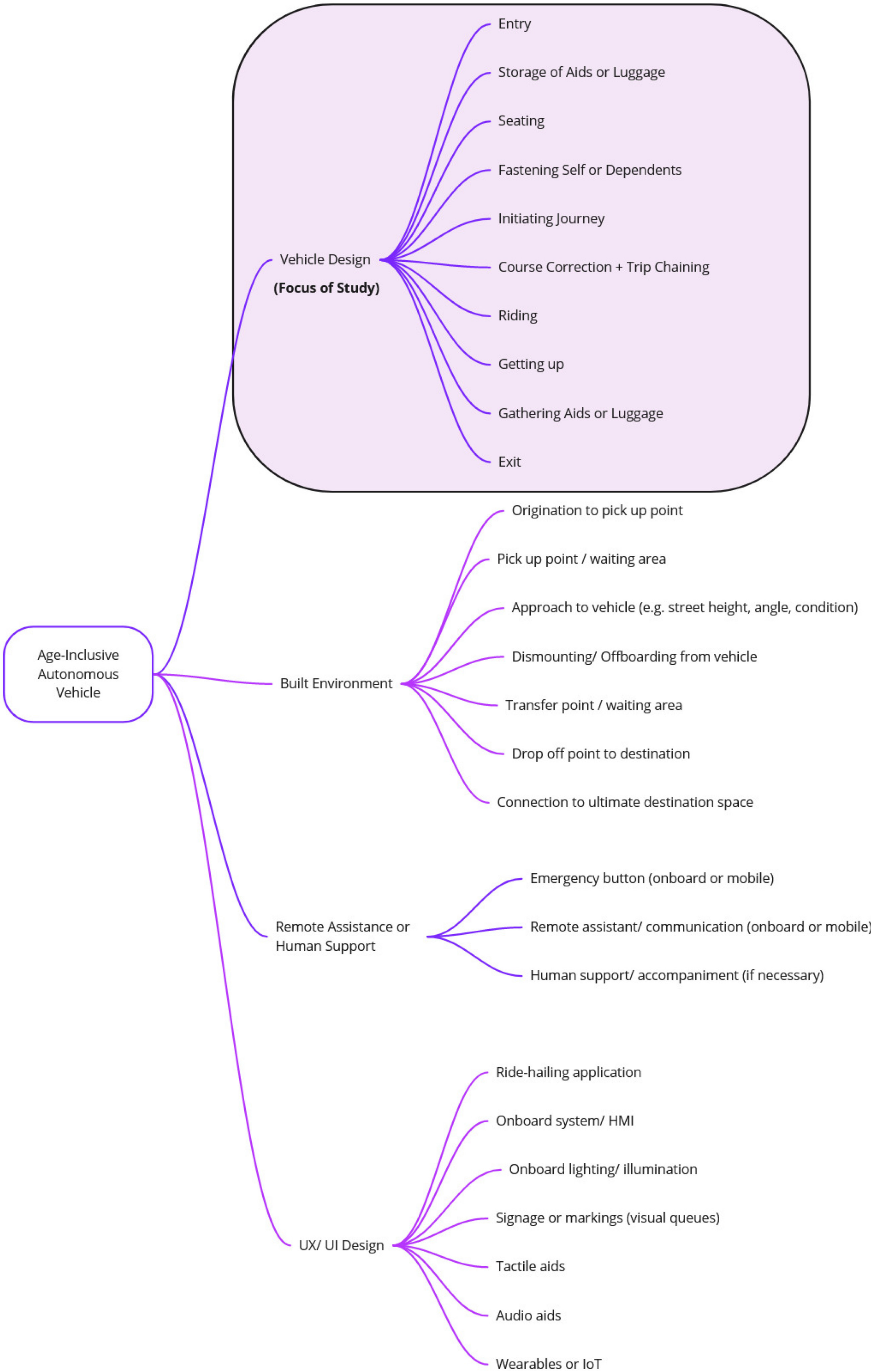

Figure 4 – Scope Illustration III

Creating the New Form Factor for AVs - 2010s

During the first wave of market excitement and rounds of investments in AV technology (approximately mid 2010s), we saw a re-imagination and redesign of the passenger vehicle. What we have seen since typically for Level 4 vehicle designs (where a human driver is no longer essential) is the replacement of the driver's seat in exchange for an extra passenger seat and the reorientation of an all forward facing vehicle to either a carriage configuration (where seats face each other - e.g., Amazon's Zoox, or GM and Honda's Cruise Origin) or a camper layout (where seats are offered all around 4 sides of the interior - e.g., Holon or Canoo prototypes).[35]

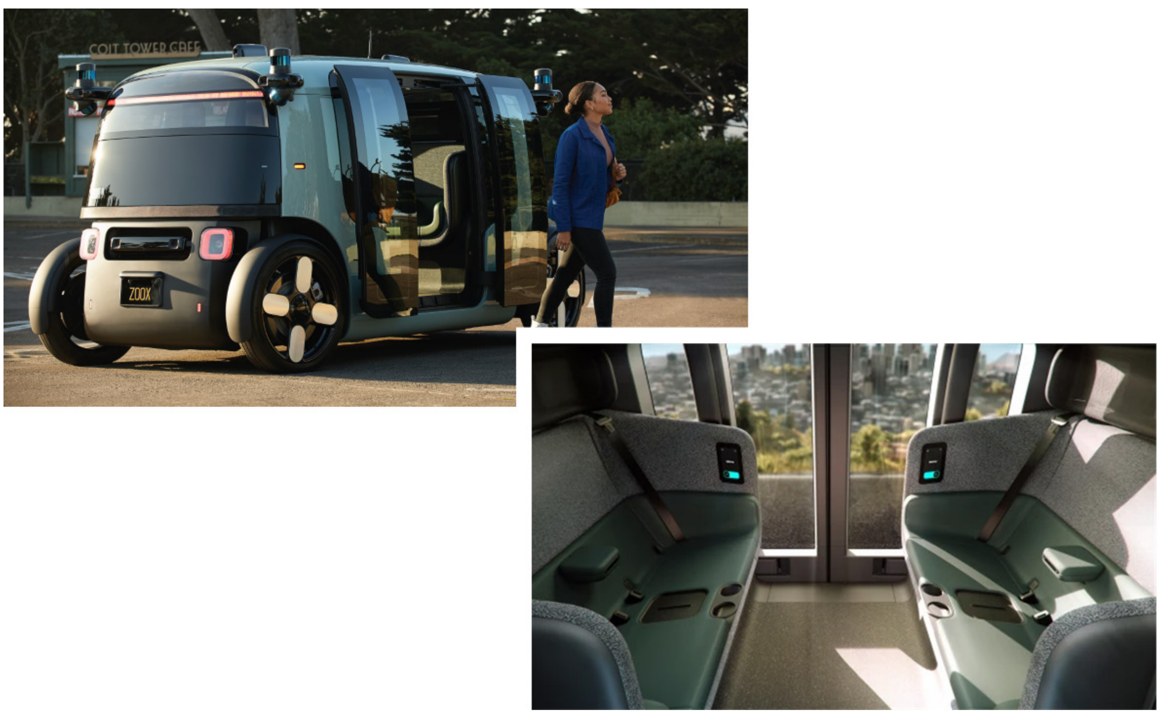

Figure 5 – New Form Factor I

[35] Level 4 or L4 vehicles are considered High Automation vehicles that do not require a human driver or driver controls on board, as opposed to L1 - L3 that are levels of automation that are designed to help a human driver make safer maneuvers. L1 - L3 are typically consider Advanced Drivers.

Above: Zoox prototype by Amazon in a coach/carriage seating configuration for on-demand shared service.[36]

Figure 6 – New Form Factor II

Above: Cruise Origin prototype by GM and Honda also in a coach configuration meant for shared on-demand mobility.

Figure 7 – Potential New Form Factor

[36] Zoox.com

Above: Canoe has a camper configuration with several seats in a circle behind the two driver seats. Canoo is an EV company that has its eyes set on some level of automation. Unlike Waymo (Google), Cruise (GM/Honda), Zoox (Amazon), Motional (Hyundai/Aptiv) who are aiming for L4 operation, Canoo has not announced L4 ambitions.[37]

Figure 8 – New Form Factor III

Above: Holon is an on-demand shared shuttle concept. Holon was unveiled at the 2023 CES convention in Las Vegas by European auto technology company, Benteler International.

In years to follow, AV makers seemed to have focused on many aspects, including resilient perception, onboard communication, safety, the automate-ability of onboard features, number of users that can be serviced, ease of user interface, overall comfort and experience, and standardizing vehicles and optimizing for fleet operations.

[37] canoo.com

On accessibility, however, there has been a wide spectrum of efforts - ranging from vehicle designs that would make it very challenging for many older adults and parents traveling with infants and small children to use - to those that had been prototyped with a narrow range special accommodations in mind. One use case that we see cutting across AV makers is wheelchair-accessible vehicles (WAVs) - aiming to provide wider than normal entry points, approach and exit ramps, turn space where needed, and independently operable wheelchair mounting and securement mechanisms.

While this sort of WAV design is certainly important and necessary, when thinking about older adult users, there is a broader set of mobility devices and aids some may use during their travels. These include but are not limited to:

- Walkers
- Rollators
- Canes
- Crutches
- Power scooters

It is worth acknowledging that there is a significant degree of heterogeneity in the physical abilities and mobility levels of 'older adults' and that the term itself has a fluid definition. For the purposes of this study, I refer to older adults loosely as those over the age of 60 following the CDC and the UN – even though a great many adults in their 60s are in prime physical condition.

Furthermore, the use or non-use of mobility aids do not encapsulate the full range of health conditions (e.g., muscular decline; arthritis; the impairment of seeing, hearing; other conditions) or the corresponding design considerations that may accompany the phenomena of aging. Some of these considerations will be discussed in the Findings an Implications Chapter, drawing upon interview data.

In addition to older adults who use mobility aids, this study also explores the AV interior design and spatial needs for parents who use strollers, infant and child seats to transport their children.[38]

Literature Review

Four (4) categories of literature are particularly pertinent to my research scope:

A) Studies focusing on how ready certain users are to adopt AVs (including across age)
B) Studies on how AVs can be made to suit the needs of aging and older adults
C) Studies on how AVs can be made to better serve persons with disabilities, and
D) Literature on 'misfitting' and social models of disability that provide a lens through which AV makers can redesign the conventional automobile to make travel inclusive.

1.1.4 Studies That Explore User Readiness of AVs

This category of AV literature is by far the most common.[39] Researchers will typically use a large sample survey to measure the level of readiness or willingness to adopt AVs

[38] Travel with larger baggage (those checked onto airplanes) is bracketed outside of this study.
[39] Hillary Abraham et al., "Autonomous Vehicles And Alternatives To Driving: Trust, Preferences, And Effects Of Age," 2017.
Jong Kyu Choi and Yong Gu Ji, "Investigating the Importance of Trust on Adopting an Autonomous Vehicle," International Journal of Human–Computer Interaction 31, no. 10 (October 3, 2015): 692–702, https://doi.org/10.1080/10447318.2015.1070549.
Koen Faber and Dea van Lierop, "How Will Older Adults Use Automated Vehicles? Assessing the Role of AVs in Overcoming Perceived Mobility Barriers," Transportation Research Part A: Policy and Practice 133 (March 1, 2020): 353–63, https://doi.org/10.1016/j.tra.2020.01.022.
Gaojian Huang et al., "Age Is More than Just a Number: The Relationship among Age, Non-Chronological Age Factors, Self-Perceived Driving Abilities, and Autonomous Vehicle Acceptance," Accident Analysis & Prevention 178 (December 1, 2022): 106850, https://doi.org/10.1016/j.aap.2022.106850.

and sometimes apply a known theoretical model of new technology adoption (e.g. Technology Adoption Model, Theory of Planned Behavior, Innovation Diffusion Theory, etc.) – running analysis across cohorts based on age, gender, wealth, education level, driving preference and ability, etc. to show who and under what conditions people

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Travis Kadylak, Shelia R. Cotten, and Chris Fennell, "Willingness to Use Automated Vehicles: Results From a Large and Diverse Sample of U.S. Older Adults," Gerontology and Geriatric Medicine 7 (January 1, 2021): 2333721420987335, https://doi.org/10.1177/2333721420987335.
Timo Lajunen and Mark J. M. Sullman, "Attitudes Toward Four Levels of Self-Driving Technology Among Elderly Drivers," Frontiers in Psychology 12 (June 23, 2021): 682973, https://doi.org/10.3389/fpsyg.2021.682973.
Chaiwoo Lee et al., "Age Differences in Acceptance of Self-Driving Cars: A Survey of Perceptions and Attitudes," in Human Aspects of IT for the Aged Population. Aging, Design and User Experience, ed. Jia Zhou and Gavriel Salvendy, vol. 10297, Lecture Notes in Computer Science (Cham: Springer International Publishing, 2017), 3–13, https://doi.org/10.1007/978-3-319-58530-7_1.
Chaiwoo Lee et al., "Acceptance of Vehicle Automation: Effects of Demographic Traits, Technology Experience and Media Exposure," Proceedings of the Human Factors and Ergonomics Society Annual Meeting 63, no. 1 (November 2019): 2066–70, https://doi.org/10.1177/1071181319631425.
Chaiwoo Lee et al., "Acceptance of Vehicle Automation: Effects of Demographic Traits, Technology Experience and Media Exposure," Proceedings of the Human Factors and Ergonomics Society Annual Meeting 63, no. 1 (November 2019): 2066–70, https://doi.org/10.1177/1071181319631425.
Chaiwoo Lee et al., "Consumer Knowledge and Acceptance of Driving Automation: Changes Over Time and Across Age Groups," Proceedings of the Human Factors and Ergonomics Society Annual Meeting 65, no. 1 (September 2021): 1395–99, https://doi.org/10.1177/1071181321651116.
Chaiwoo Lee and Joseph F. Coughlin, "PERSPECTIVE: Older Adults' Adoption of Technology: An Integrated Approach to Identifying Determinants and Barriers," Journal of Product Innovation Management 32, no. 5 (2015): 747–59, https://doi.org/10.1111/jpim.12176.
Jein Park and Semi Han, "Investigating Older Consumers' Acceptance Factors of Autonomous Vehicles," Journal of Retailing and Consumer Services 72 (May 1, 2023): 103241, https://doi.org/10.1016/j.jretconser.2022.103241.
Martina Raue et al., "The Influence of Feelings While Driving Regular Cars on the Perception and Acceptance of Self-Driving Cars: Feelings and Self-Driving Cars," Risk Analysis 39, no. 2 (February 2019): 358–74, https://doi.org/10.1111/risa.13267.
Ericka Rovira et al., "Looking for Age Differences in Self-Driving Vehicles: Examining the Effects of Automation Reliability, Driving Risk, and Physical Impairment on Trust," Frontiers in Psychology 10 (2019), https://www.frontiersin.org/article/10.3389/fpsyg.2019.00800.
Alexa L. Siegfried et al., "Older Adult Willingness to Use Fully Autonomous Vehicle (FAV) Ride Sharing," Geriatrics 6, no. 2 (April 29, 2021): 47, https://doi.org/10.3390/geriatrics6020047.
J. Yang and Joseph F. Coughlin, "In-Vehicle Technology for Self-Driving Cars: Advantages and Challenges for Aging Drivers," The Korean Society of Automotive Engineers, March 2014, https://dspace.mit.edu/handle/1721.1/105917.

are more willing to try a new technology. Lee et al., (2017) ask, for example, 'Are older adults willing to use autonomous vehicles and/or alternatives to driving that may increase mobility?,' 'How are consumers learning about in-vehicle technologies?,' 'How would they prefer to learn?'[40] Siegfried et al., (2021) found that in regards to AVs, older adults wanted to see proven safety and performance records, followed by dependability and accuracy of AV ride sharing. Park and Han (2023) observed that despite the inherent benefits AVs can provide to older adults who go through driving cessation and its adverse effects on the quality of life, the Baby Boomer cohort is reluctant to trust and adopt this technology.[41] Raue et al., (2019) go further to explain that one contributor to this reluctance comes from a preference of long-time drivers to prefer to remain in the driver's seat and in control rather than become a passive passenger – as a form of loss aversion.[42]

This body of literature, however, largely takes a 'wait and see' approach to the technology instead of applying a critical lens on how vehicles can be reshaped along with automation to meet the mobility needs of those who are currently underserved. Nevertheless, they at times offer valuable lessons to researchers on what patterns and trends can be found across different user segments.

[40] Abraham, H., Lee, C., Brady, S., Fitzgerald, C., Mehler, B., Reimer, B., & Coughlin, J. F. (2017). Autonomous Vehicles and Alternatives to Driving: Trust, Preferences, and Effects of Age. 16

[41] Park, J., & Han, S. (2023). Investigating older consumers' acceptance factors of autonomous vehicles. Journal of Retailing and Consumer Services, 72, 103241. https://doi.org/10.1016/j.jretconser.2022.103241.

[42] Raue, M., D'Ambrosio, L. A., Ward, C., Lee, C., Jacquillat, C., & Coughlin, J. F. (2019). The Influence of Feelings While Driving Regular Cars on the Perception and Acceptance of Self-Driving Cars: Feelings and Self-Driving Cars. Risk Analysis, 39(2), 358–374. https://doi.org/10.1111/risa.13267

1.1.5 AV Studies Related to Aging

This body of literature examines AV features and designs that would make mobility experiences more inclusive of older riders. [43] Yang and Coughlin, for example, look at common travel patterns and behaviors of older adults and write about what automation features would provide overall benefits around safety, comfort, driving efficiency, etc.[44]

The 2021 AARP report, "Older Adults, New Mobility, and Automated Vehicles" lays out a proposed 'Framework for Older Adult Mobility Factors' Fraade-Blanar et al., "Older Adults, New Mobility, and Automated Vehicles.". The framework's 23-line items include aspects such as:

- Smartphone access and use, online payments, digital trust
- Affordability
- Physical barriers, language barriers, cognitive barriers
- Non-crash related safety (e.g., fall risk or injury risk while entering, exiting, or riding)
- Interpersonal security (e.g., crime or aggression between passengers)
- Road safety
- Service availability (and bias or prejudice in availability), reliability, consistency
- Built environment design (e.g., street, sidewalk, curbs)
- Accommodation of goods or aids, etc.

[43] Laura Fraade-Blanar et al., "Older Adults, New Mobility, and Automated Vehicles" (Washington, DC: AARP Public Policy Institute, February 17, 2021), https://doi.org/10.26419/ppi.00132.001.
Samip Jain, "An Inclusive Design Framework for Autonomous Vehicles to Create Valuable Experience for Elderly" (Thesis, Massachusetts Institute of Technology, 2020), https://dspace.mit.edu/handle/1721.1/132829.

[44] Yang and Coughlin, "In-Vehicle Technology for Self-Driving Cars." (Massachusetts Institute of Technology, 2014), https://dspace.mit.edu/handle/1721.1/105917.

The report, however, does not dive deep into any individual element, since it is meant to be kept high level. One benefit is that it allows researchers to take one or more of the frameworks pillars and investigate much deeper into how to enhance AV experiences. In this thesis, I zoom in one in-vehicle spatial elements as it relates to users of AVs.

1.1.6 AV Studies Related to Disabilities

There is also quite a body of literature that explores the utility of AVs for persons with disabilities.[45] One common theme that emerges in articles prior to 2021 is advocacy for

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[45] Roger Bennett, Rohini Vijaygopal, and Rita Kottasz, "Attitudes towards Autonomous Vehicles among People with Physical Disabilities," Transportation Research Part A: Policy and Practice 127 (September 1, 2019): 1–17, https://doi.org/10.1016/j.tra.2019.07.002.
Roger Bennett, Rohini Vijaygopal, and Rita Kottasz, "Willingness of People with Mental Health Disabilities to Travel in Driverless Vehicles," Journal of Transport & Health 12 (March 1, 2019): 1–12, https://doi.org/10.1016/j.jth.2018.11.005.
Roger Bennett, Rohini Vijaygopal, and Rita Kottasz, "Willingness of People Who Are Blind to Accept Autonomous Vehicles: An Empirical Investigation," Transportation Research Part F: Traffic Psychology and Behaviour 69 (February 1, 2020): 13–27, https://doi.org/10.1016/j.trf.2019.12.012.
Musfiqur Rahman Bhuiya and Jun Liu, "Autonomous Vehicle - Heaven or Hell for People with Disability: A Study from Literature," SSRN Scholarly Paper (Rochester, NY, May 8, 2022), https://doi.org/10.2139/ssrn.4441972.
Henry Claypool, Amitai Bin-Nun, and Jeffrey Gerlach, "Self-Driving Cars: The Impact on People with Disabilities," Ruderman Family Foundation (blog), 2017, https://rudermanfoundation.org/white_papers/self-driving-cars-the-impact-on-people-with-disabilities/.
Paige Cordts et al., "Mobility Challenges and Perceptions of Autonomous Vehicles for Individuals with Physical Disabilities," Disability and Health Journal 14, no. 4 (October 1, 2021): 101131, https://doi.org/10.1016/j.dhjo.2021.101131.
Susana Costa et al., "Tackling Autonomous Driving Challenges – How the Design of Autonomous Vehicles Is Mirroring Universal Design," in Advances in Human Factors and Systems Interaction, ed. Isabel L. Nunes, Advances in Intelligent Systems and Computing (Cham: Springer International Publishing, 2019), 134–45, https://doi.org/10.1007/978-3-319-94334-3_15.
Alberto Dianin, Elisa Ravazzoli, and Georg Hauger, "Implications of Autonomous Vehicles for Accessibility and Transport Equity: A Framework Based on Literature," Sustainability 13, no. 8 (January 2021): 4448, https://doi.org/10.3390/su13084448.
Brad E. Dicianno et al., "Systematic Review: Automated Vehicles and Services for People with Disabilities," Neuroscience Letters 761 (September 14, 2021): 136103, https://doi.org/10.1016/j.neulet.2021.136103.
Jinuk Hwang, "Improving Mobility of People with Disabilities: The Potential of Autonomous Vehicle

states not to legally require AVs to have passengers who have drivers licenses, since this requirement would curtail AV benefits to many people with disabilities who are not licensed. With increased demonstration of L4 operations, this concern has been subdued to some degree.

Musfiqur Rahman Bhuiya, a graduate student from the University of Alabama, did thorough work in summarizing the state of innovation for accessibility-enabling transportation technology as of 2022.[46] Participatory studies involving focus groups like the one by Hwang et al., capture key frustrations with the transportation status quo (e.g. limited space in transit vehicles and poor service toward persons with disabilities) and expectations for future AVs (e.g. greater freedom of travel using AVs but also potential

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Transportation Service and the Role of the Built Environment" (Thesis, 2020), https://oaktrust.library.tamu.edu/handle/1969.1/192324.
Jinuk Hwang et al., "A Focus Group Study on the Potential of Autonomous Vehicles as a Viable Transportation Option: Perspectives from People with Disabilities and Public Transit Agencies," Transportation Research Part F: Traffic Psychology and Behaviour 70 (April 1, 2020): 260–74, https://doi.org/10.1016/j.trf.2020.03.007.
Jinuk Hwang et al., "People with Disabilities' Perceptions of Autonomous Vehicles as a Viable Transportation Option to Improve Mobility: An Exploratory Study Using Mixed Methods," International Journal of Sustainable Transportation 15, no. 12 (October 1, 2021): 924–42, https://doi.org/10.1080/15568318.2020.1833115.
Eva Kassens-Noor et al., "Autonomous Vehicles and Mobility for People with Special Needs," Transportation Research Part A: Policy and Practice 150 (August 1, 2021): 385–97, https://doi.org/10.1016/j.tra.2021.06.014.
Daniel Leite Mesquita et al., "Autonomous Vehicles and People with Disabilities: A Scientometric and Integrative Analysis of the Literature," Journal of Scientometric Research 11, no. 3 (January 6, 2023): 332–43, https://doi.org/10.5530/jscires.11.3.36.
Benjamin Nanchen et al., "Perceptions of People with Special Needs Regarding Autonomous Vehicles and Implication on the Design of Mobility as a Service to Foster Social Inclusion," Frontiers in Human Dynamics 3 (2022), https://www.frontiersin.org/articles/10.3389/fhumd.2021.751258.
Ronik Ketankumar Patel et al., "Exploring Preferences towards Integrating the Autonomous Vehicles with the Current Microtransit Services: A Disability Focus Group Study," June 4, 2021, 355–66, https://doi.org/10.1061/9780784483534.031.
Patrice D. Tremoulet et al., "Transporting Children in Autonomous Vehicles: An Exploratory Study," Human Factors 62, no. 2 (March 1, 2020): 278–87, https://doi.org/10.1177/0018720819853993.
[46] Bhuiya et al. "Autonomous Vehicle - Heaven or Hell for People with Disability: A Study from Literature": SSRN. Accessed July 2, 2023. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4441972.

communication errors and lower levels of support from removing human operators completely).[47] Another mixed methods study by Hwang et al, captured interesting insights via its stated preference survey (n= 222).[48] Some survey prompts included:

"AVs could solve the transportation problems of people with disabilities like me" (9% disagree or strongly disagree, 74% agree or strongly agree, 17% neither)
"AVs would not be accessible for all if there is no human operator" (27% in the disagree spectrum vs. 45% in the agree spectrum with 28% in neither)

Another study worth noting was done by a public policy master student from the Kennedy School, Katie Monroe. Monroe outlines the broad categories of disabilities and distinguishes aging as a phenomenon distinct from disabilities but nevertheless one that may present functional limitations to travel.[49] Monroe also grounds her analysis framework in a 'social model' of disability, which contrasts with a more conventional 'medical model' of disability. In the medical model, a person's disability is the root of the problem and is seen as something to be cured or overcome. By contrast, in the social model, disability and disablement stems from systemic barriers that can, for example, be found in the built environment, in products etc. that do not meet the needs of people's unique bodies.[50]

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[47] Hwang, et al. "A Focus Group Study on the Potential of Autonomous Vehicles as a Viable Transportation Option: Perspectives from People with Disabilities and Public Transit Agencies." Transportation Research Part F: Traffic Psychology and Behaviour 70 (April 1, 2020): 260–74. https://doi.org/10.1016/j.trf.2020.03.007.
[48] Hwang, et al. "People with Disabilities' Perceptions of Autonomous Vehicles as a Viable Transportation Option to Improve Mobility: An Exploratory Study Using Mixed Methods." International Journal of Sustainable Transportation 15, no. 12 (October 1, 2021): 924–42. https://doi.org/10.1080/15568318.2020.1833115.
[49] Monroe. "Autonomous Vehicles and Disability Access: Considerations for Boston." (June 9, 2019).
[50] Perry, S. B. &. R. (2021). "The Social Model of Disability Explained". Social Creatures. https://www.thesocialcreatures.org/thecreaturetimes/the-social-model-of-disability

1.1.7 Disability Literature on 'Misfits'

Rosemarie Garland-Thomson's notion of 'misfitting' is foundationally critical to this thesis work. In her own words, her article 'Misfits' is described as "an account of a dynamic encounter between flesh and world."[51] As there is a misfit between a square peg in a round hole, disability is a relational reality emerging from the misfit between the world we live in (constructed or natural) and the particularities of our bodies.[52] In the context of this thesis, this worldview can be used to illustrate the misfit between traditional vehicle designs and certain bodies (e.g. wheelchair users, children who require seat adjustments, etc.) as well as the misfit between the urban built environment and users of rollators, for example. The same paradigm can be used to reimagine what it would take to make vehicles and transportation experiences more suited to their needs. Though originating from disability studies, this framework has application far beyond the one discipline in thinking about how designers and technologists can develop products with greater/ broader consumer fit.

Research Questions

Informed by prior literature and gaps in existing work, this study asks "What challenges might users of mobility devices face or anticipate with using shared on-demand autonomous vehicles (particularly in new form factors)?" and "What spatial allowances and features should vehicle designers consider when re-imagining the interior space of

[51] Garland-Thomson, Rosemarie. "Misfits: A Feminist Materialist Disability Concept." Hypatia 26, no. 3 (2011): 591–609. https://doi.org/10.1111/j.1527-2001.2011.01206.x.

[52] One point that Garland-Thomson tries to clarify is that fitting and misfitting do not stem from societal attitudes alone. She says "Misfitting operates independently of oppressive agents or even groups who might exercise active antipathy or discrimination. A wheelchair user, for instance, might be socially accepted in a workplace, but if the only way to get to the office is via stairs, a wheelchair user will not have access to the economic benefits a stair climber has. Similarly, a blind person is disadvantaged in a world that demands reading printed text in order to fully participate in the public sphere." p. 602.

autonomous vehicles?" As a corollary, where might mobility devices be stored and secured while the vehicle is in motion?

Hypothesis

At the outset of the study, the initial hypotheses were that.

- **H1.** Respondents would require additional space for their luggage or travel aids, and would not frequently use robotaxi services if they are unable to occupy space additional to their own seats.
- **H2.** Users would want to place their mobility devices in the trunk or a separate compartment from the passenger space.
- **H3.** Users would prefer to fold away or sit apart from all forms of mobility aids due to safety concerns.
- **H4.** Regarding accessibility features - There may be a small number of common requests (e.g., adjustability of font size on display and volume due to the prevalence of visual and hearing impairment with age), but there will also be great heterogeneity in special requests due to differences in health conditions among older adults.

2. Chapter Two - Methods and Approach

Methods

This study draws on a combination of user (20) and industry expert (24) interviews, as well as observing the behaviors of users in scenarios such as staging, boarding, and exiting conventional vehicles. In order to learn the experiences, needs, challenges, and aspirations of future AV users, I interviewed 20 participants in one-hour semi-structured interviews via Zoom between November 2022 and March 2023.[53]

The MIT AgeLab Database, containing approximately 15,000 contacts, served as a starting point for user interviewee recruitment. Using a pre-interview survey with 16 screening questions created in Qualtrics, the research team and I then used Constant Contact (an automated email distribution tool) to reach out to 536 potential candidates. 506 emails were delivered successfully. Of the 506, we received a total of 118 complete responses (discarding incomplete ones), and met with a total of 20 participants. In the project design phase, I scoped a range between 15-25 interviews, but began to see a saturation of narratives around major themes on useability and interior design around the 13th/14th participant.

The intent behind the screening questionnaire was twofold:

1. To recruit interview candidates that could speak intimately to the general and spatial needs of using mobility aids/devices, strollers, and wheeled luggage - by direct user experience or by being in a caregiving capacity observing and aiding users, and
2. To keep the interviewee pool relatively balanced in terms of gender, and provide a mix of urban vs. suburban participants.

[53] Participants were compensated for their time. The interview guide with AV illustrations is included in the Appendix section.

The questionnaire can be found in the Appendix section, and the table below shows a breakdown of participant characteristics:

Characteristics	Percentage	Number (out of 20)
Male	40%	8
Female	60%	12
Age (18 - 39)	15%	3
Age (40 - 54)	10%	2
Age (55 - 64)	30%	6
Age (65 - 74)	35%	7
Age (75+)	10%	2
Mobility Device/Aid Used[54]	100%	20
Urban Residence	35%	7
Suburban Residence	55%	11
Rural Residence	10%	2
Drives 5+ times/week	50%	10
Drives 3-4 times/week	30%	6
Drives 0-2 times/week	20%	4

Limitations

This study focuses on and draws upon participants mainly from the New England area of the United States. Therefore, other studies that sample participants from different national or global regions may observe different preferences and behavioral outcomes. Another item to disclose in participant selection is that the final selection was not random. Though there is a degree of randomization at the initial stage of email

[54] Participants were asked in the pre-interview screener whether they or anyone in their immediate household has used in the past 12 months any of the listed mobility aids or devices when moving about (with an additional option to describe any other items that were not listed). For the question, please see Q4 and Q7 in the Screening Questions within the Appendix section.

distribution, interviewees were subsequently filtered and chosen based on a set of desired characteristics, beginning with the use of mobility aids and later balancing for a relatively balanced gender mix. Next, participants include a mix of caregivers who provide care to users of mobility devices as well as direct users. Given the small sample size, any observation or extrapolated insight cannot be generalized at a national scale.

What Type of Questions Were Asked and How?

Each participant was asked a set of context setting questions and then to share their opinions on how they (or their care recipients) would interact with AVs - with visual references to aid their framing of space and travel through that space. The central question driving the interview guide was "Will new on-demand, shared L4 vehicle formats make it easier or harder for those using mobility aids/devices get around, and if there are perceived challenges, then how might users tell us about features they need to travel and travel comfortably? As part of this line of inquiry, I asked questions on the space required to enter, ride, and exit the vehicle while using mobility aids/devices, as well as where and how participants wished to store those devices in relation to where they sat.

Below is a non-exhaustive set of questions and visual references used during each interview.[55]

- **Place, Mode** - Where do you live, and how do you typically get around?
- **Range** - What is your typical travel radius (in miles)?
- **Family** - Who do you live with?
- **User Journey** - Could you describe a typical trip from the moment you decide to make a trip, how you get ready to the moment you arrive at a set destination?

[55] For the full interview guide, see the Appendix.

- **Pain points** - What are your greatest pain points? What more do you aspire to do - mobility-wise?
- **Decision** - What factors weigh in when making a decision about how to get to a place?
- **Items for Travel + Mobility Aid** - What do you usually take with you?
    - You have indicated that you or a household member has traveled with a mobility aid/device in the past 12 months. Remind me what it was, and if comfortable, would you mind talking about that?
    - How does it currently shape the ways in which you're able to travel, and ways you're unable to travel?
    - How important is it to have that when traveling?
    - How likely would you be to make the trip if you couldn't take it with you?
    - Where do you store it?
    - How much space do you need for that?
    - Were you ever unable to travel because of this space requirement?
    - What other needs or accommodations are useful in enabling your travel /provide you comfort?

- **Human Assistance**
    - Are there ways in which drivers offer you assistance prior to, during, or at the conclusion of your trip?
    - How do you imagine the same task may be carried out in the absence of a human driver?
- **Pros and Cons**
    - What do you perceive the main societal, personal benefits autonomous vehicles will bring?
    - What do you see as the potential downsides?

- **Discussion on AV Prototypes**
    - If you were to redesign or modify, what features would you introduce and why? What do you think would be the top 2-3 things you would change or improve? Why?

Visual References for Discussion used approximately at the 30-40 min mark.
(Figures 5 to 8 shown previously)

In using some of the visual references above and talking about potentially useful features, questions were left open-ended to illicit as much content and reflection in response to the references. In some interviews - particularly in cases where the interviewee was engaged and talkative, participants were simply asked to provide their reaction to the interior visual in reflection to the conversation we had been having leading up.

Overall, the use of visual focal points helped to ground the participant's abstract imagination of a future AV to a form where they could imagine themselves moving through that form. In at least two instances, participants did express difficulty in fully envisioning interacting with the AV via image instead of in-person, which is one constraint of this study. A UX researcher from a leading AV maker stated that user touchpoints are observed in a variety of ways - including the use of sensors as well as by 'riding along' with the user. However, the limiting factor here based on my literature review, is that detailed observations or age-related insights have not been widely published drawing on direct user testing.

Industry Expert Interviews

Non-user interviews draw upon product owners/managers, UX designers and researchers, policy leads, and engineering leads from leading American autonomous vehicle (AV) makers; AV regulators/policymakers at federal, state, and municipal levels;

and an accessibility designer. Snowball sampling was the primary approach utilized.[56] Twenty-four (24) semi-structured 30-min interviews were conducted between April 2022 and April 2023 - some with follow-ups and document requests.

Observational Primary Research

Observing people, place, and vehicles also formed an important component of this study, in addition to ad hoc interviews. During the primary data gathering period (April 2022 - April 2023), I observed a variety of vehicle models and interiors across approximately 120 Lyft and Uber rides in New England as well as engaging in conversation with some of the drivers about vehicle features, amenities, and rider behaviors and needs.

In order to get a better understanding of autonomous rides, the author also visited an urban AV testing environment in Las Vegas, Nevada, between October 1-2, 2022 - observing five (5) different Pickup/Drop-Off (PU/DO) zones, passenger behaviors in these zones, as well as taking nine (9) AV robotaxi rides accompanied by safety operators. PU/DO zones included two at Mandalay Bay, one at Luxor, another at the Aria, and one at the Park MGM.

[56] Snowball sampling or chain sampling is a method by which additional recruitment is done by referral of the previous interviewee. For more details on snowball sampling, see: What Is Snowball Sampling? | Definition & Examples. https://www.scribbr.com/methodology/snowball-sampling/

Figure 9 – Photos of Robotaxi Rides (Motional/Lyft)

Between January and April 2023, the author also examined a variety of devices and mobility aids to include a variety of:

- Walkers and rollators
- Canes and crutches
- Infant seats, booster seats, car seats
- Strollers, including umbrella strollers, full size strollers, prams, modular travel systems, and double strollers
- Wheelchairs

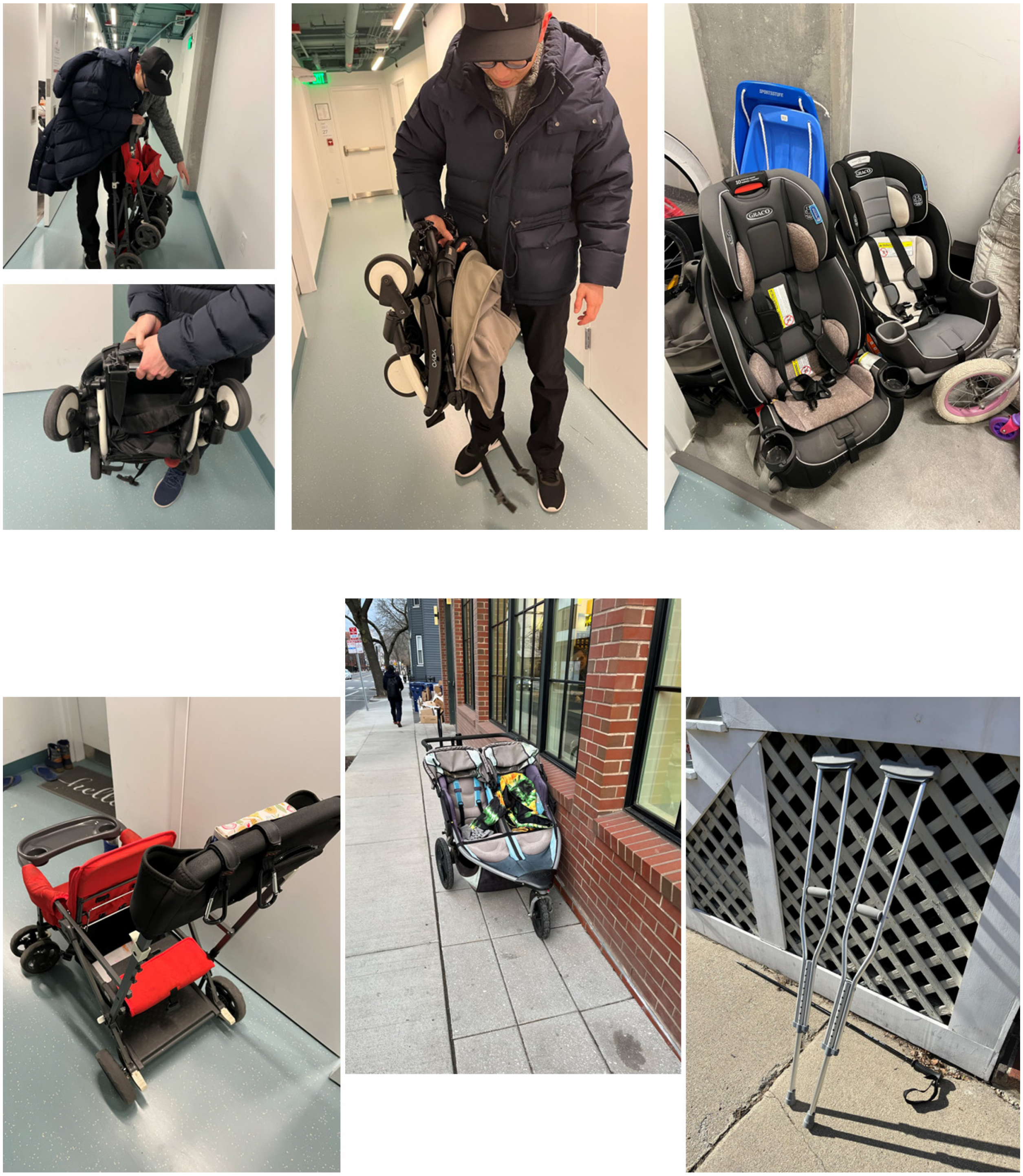

Figure 10 – Photos of Observational Research

In the following chapters, please note that user interview participants will be referred to synonymously as 'participants,' 'respondents,' or 'interviewees,' whereas industry interviewees will be referred to as 'industry experts' or 'industry leaders.'

3. Chapter Three - Findings and Potential Implications

This chapter provides an overview of insights gleaned from primary user interviews. Findings and potential implications are organized in the following two (2) ways:

1. Participant insights organized by 'touchpoints' with the vehicle (laid out at a high level in the following diagram)
2. A review of the original hypotheses against what participants had to say about them,

User Touchpoints with The On-Demand Shared Autonomous Vehicle

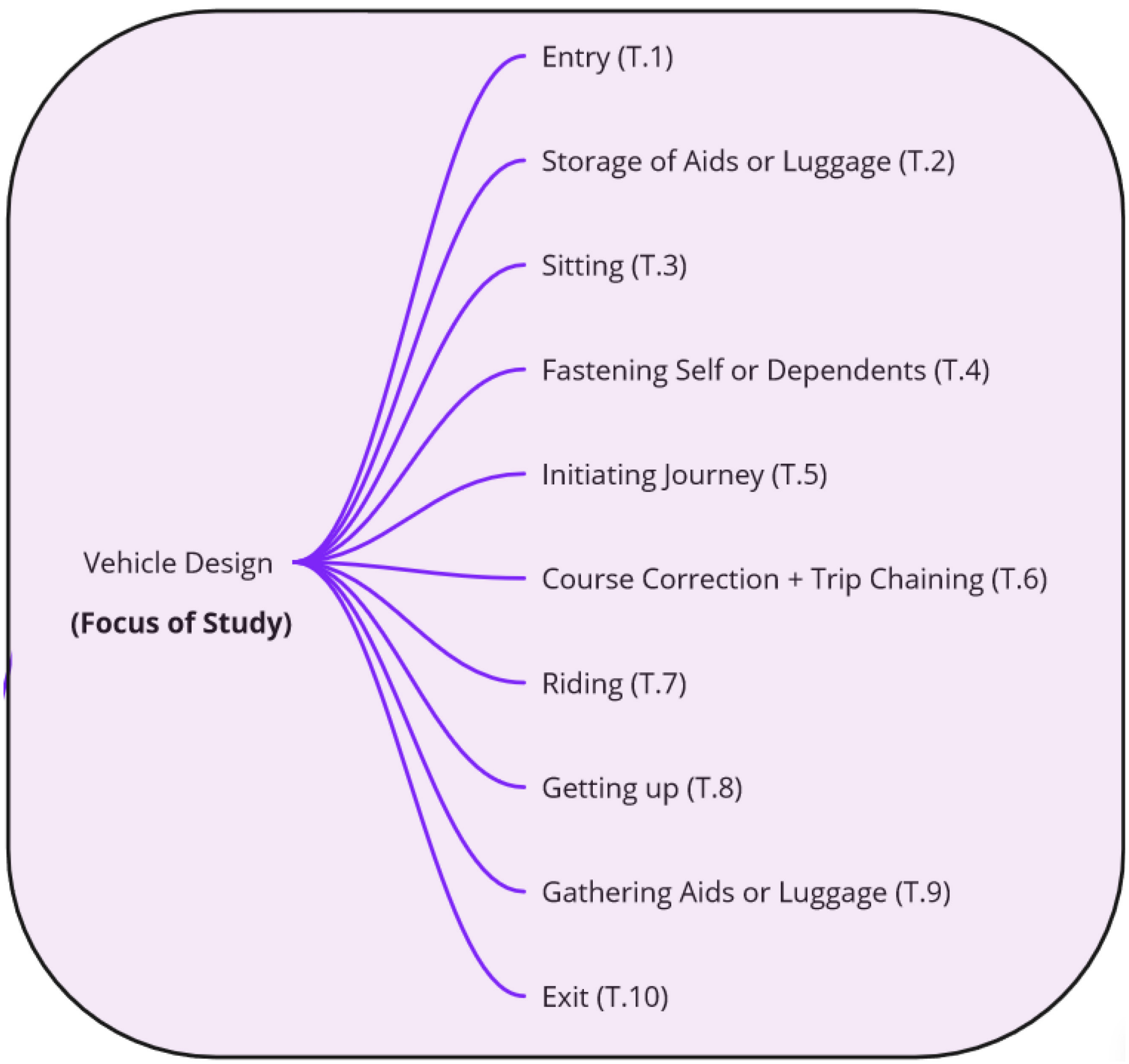

Figure 11 - User Touchpoints with The On-Demand Shared Autonomous Vehicle

Diagram Source: Created by David Hong. 2023

Descriptions below are meant to be illustrative rather than comprehensive, and will require more input during direct user testing interacting with vehicles. Having said that, this section aims to distill some key insights for each of the main user touchpoints with the vehicle itself. Each of the ten (10) touchpoints - labeled T.1 through T.10 include subsections on 'needs', 'questions, concerns', and 'feature suggestions' raised by participants.

T.1 Entry into the Vehicle (T.1)

T.1.1 Needs

This is the touchpoint where the built environment (e.g., road, street, curb, parking lot, PU/DO zone, etc.) meets the vehicle and the user navigates the fit or misfit of these boarding areas vis-à-vis their body. Rosemarie Garland-Thomson tells us that "disability is created not by impairment [simply of the body] but by a mismatch between bodies and the environments in which they exist."[57] There are many hostile elements of the built environment that lie beyond the scope of this study; however, it is important to acknowledge once more that a user journey is not neatly divided into the road vs. the vehicle but that every point of pain or enjoyment along the way contributes to the overall quality of user experience.

Much of how the built environment meets the AV is up to infrastructure maintenance, accessible design, curb management, and effective enforcement by the municipal entity. Having said that, the AV fleet operator also has a key role in facilitating this connection - at minimum in establishing the geofenced Pickup and Dropoff (PU/DO) areas that determine how far and to where a user will have to go to meet the AV, as well as how

[57] Garland-Thomson, Rosemarie. "Misfits: A Feminist Materialist Disability Concept." Hypatia 26, no. 3 (2011): 591–609. https://doi.org/10.1111/j.1527-2001.2011.01206.

the vehicle physically meets the environment. In the 2021 AARP study on new mobility and AVs, Fraade-Blanar and others highlight how close some older adults need their trips to begin and end to the origination and destination points for AV services to be a safe and viable proposition.[58] They use the term "door-to-door" service to describe this first-and-last-mile transportation need in contrast to "curb-to-curb."[59] A pertinent question for users with mobility-related challenges or disabilities is whether on-demand AV services on average will increase, keep same, or reduce the distance between the origination vs. pickup points and destination vs. drop off points compared to their human-driven TNC[60] counterparts. According to a public policy manager at a leading AV firm, it is probable that these distances would increase in the short term by choosing PU/DO points that the AV would have relative ease negotiating in a multimodal environment (e.g., against heavy pedestrian or cyclist flows). In fact, the San Francisco Municipal Transportation Authority (SFMTA) observed and noted in a November 2021 public letter that six pick-up and six drop-off events in a video posted by an AV company currently operating in SF that each of these stops were made in travel lanes rather than in parking lanes adjacent to the curb.[61]

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[58] Fraade-Blanar, Laura, Nico Larco, Ryan Best, Tiffany Swift, Marjory S. Blumenthal, and AARP Public Policy Institute. "Older Adults, New Mobility, and Automated Vehicles." Washington, DC: AARP Public Policy Institute, February 17, 2021. https://doi.org/10.26419/ppi.00132.001.
[59] Ibid.
[60] TNCs are transportation network companies - e.g., Uber, Lyft.
[61] "SFMTA's Comments on Cruise Application for Driverless Deployment Permit – Tier 3 Advice Letter" November 29, 2021. https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/consumer-protection-and-enforcement-division/documents/tlab/av-programs/phase-i-av-deployment-program-al-status/2021-11-05-protests-and-responses-al-1-cruise-driverless-deployment-permit.zip.

Figure 12 – Photo of AV drop-off (double parking)

If all pick-up and drop-offs were done in the middle of the road, this would be detrimental to many of the subjects of our study who would not only be inhibited by the curb, but by oncoming bikes, micromobility modes, cars, as well as often not being able to navigate between narrowly parked vehicles, among other hindrances. Further study and validation would be needed to assess current capabilities and practices across operators. The question becomes even more nuanced when we think about whether the AV will be able to place a rollator or wheelchair user to exit from the vehicle to directly on top of a curb or at the base of a curb cut area rather than on the road between vehicles while double parking itself. As of April 2023, what we know is that neither of the two commercially permitted AV operators in SF is making ramped curbed connections from the vehicle.

Returning back to the user and the vehicle itself, interview participants indicated that the <u>vehicle entrance</u> would need to be wide enough to allow for wheelchairs, larger strollers, and rollators to enter. Standard measurements can be found in reference sources such as Ernst Neufert's Architect's Data[62] and the ADA.[63] The ADA recommends an accessible route to be at least 915 mm or 36 inches wide and Neufert recommends at least 900 mm or 35 inches. The turning radius inside is just as important. The ADA recommends a minimum circular turning space of 1525 mm (or 1.525 meters or 5 feet) and Neufert recommends a minimum of 1.5 meters or 4.9 feet. See an illustrative figure below from Neufert's *Data Architect.*

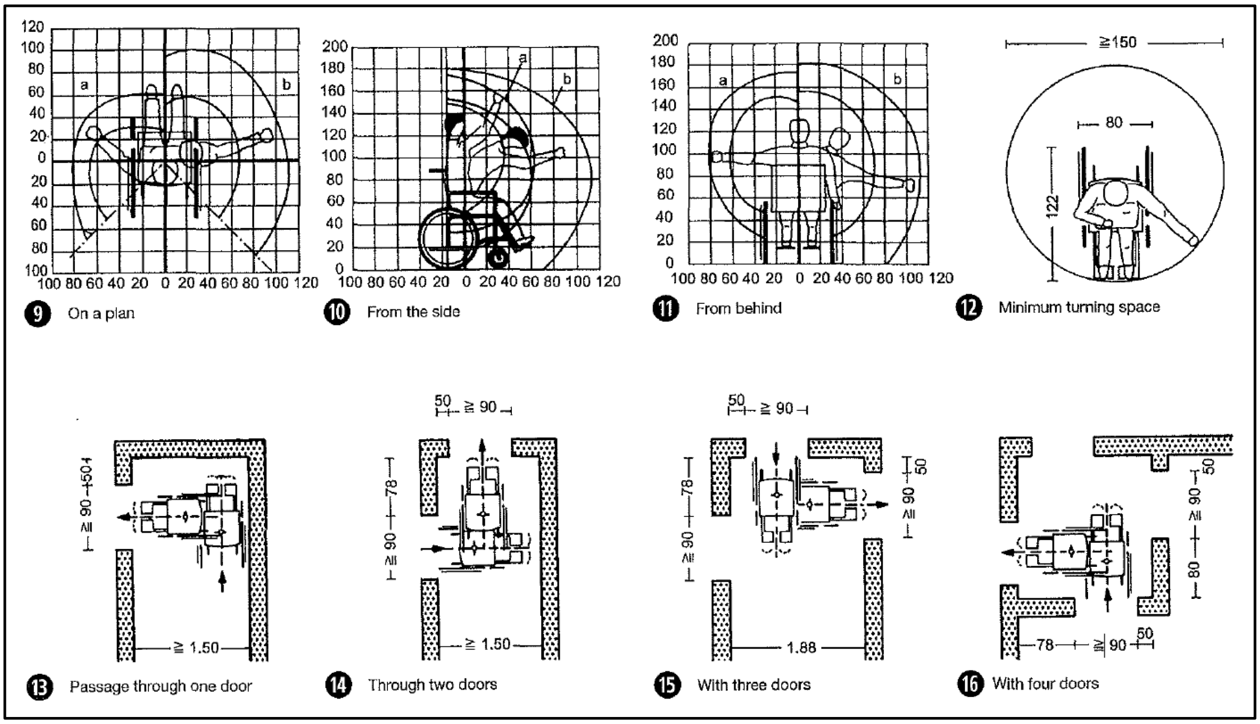

Figure 13 – Wheelchair turning radius | Source: Ernst Neufert. Architect's Data. 4th edition. Page 21.

On average, the 35–36-inch opening would also allow for the passage of power scooters as well as wider strollers (including double seaters that are wider than single occupant strollers). Wheeled aids would also require a ramp that met standard specs (e.g., a ramp run with a slope no steeper than 1:12 according to the ADA and a maximum slope of 6% for Neufert), and that would self-deploy and retract without human intervention -

[62] Neufert, E. (2019). Architects' Data. John Wiley & Sons.
[63] U.S. Access Board. Americans with Disabilities Act Accessibility Standards. https://www.access-board.gov/ada/

if the normal use case were designed for independent rider use.[64] Ramps might also have small side guardrails so that users do not accidentally mismaneuver off the ramp on boarding or exit.

Users of rollators or walkers also indicated that they would benefit from ramps. However, users of canes, crutches, strollers, and wheeled luggage generally indicated that they would try to climb up the vehicle with support if a) the clearing height was not a major obstacle, and b) there was a vertical handlebar to hold and pull on along the entryway. Nearly all study participants noted that they would desire a support mechanism, such as a handle or bar at the ingress and egress points - reflecting upon their current practices. Arthritis becomes increasingly common with age - with more than half of adults over 65 being diagnosed with it[65] - and so interviewees frequently shared that they would pull or push on inner door handles or the dash, grab door frames, etc. when moving in and out of conventional vehicles. A comparable passenger vehicle precedent is the London Black Taxis, which have clearly marked yellow handles above the doorways.

[64] Neufert, E. (2019). Architects' Data. John Wiley & Sons.
U.S. Access Board. Americans with Disabilities Act Accessibility Standards. https://www.access-board.gov/ada/

[65] "Among adults aged 65 and older, 50% report ever having been diagnosed with arthritis. Among adults aged 45 to 65 years, 31% report ever having been diagnosed with arthritis."
4 Facts to Know. (2019, May 17). Centers for Disease Control and Prevention. https://www.cdc.gov/arthritis/communications/features/4things.htm.


[66]

Figure 14 – London Black Taxi Interior | Photo Credit: Nissan

One important observation about turning within the vehicle is the following: walker users noted that they would not be able to exit out of a vehicle backwards. Presuming that in most urban scenarios - even with doors situated on both sides - that passengers would exit on the curb to the right (in North America), mobility aid users would need to fully reorient before exiting the vehicle. This generally holds for strollers, rollators, as well as for seated aids.

Finally, several participants who used mobility aids during their post-surgery recovery period (which sometimes spanned from 1.5 - 3+ months) shared that their movement was much slower than they were pre-operation. Anecdotally, one older adult who used a set of crutches and then a cane following a knee operation said they moved at less than half their usual speed with crutches and marginally faster with a cane. On average, those who rely on mobility aids will require more lead time to entry and potentially during boarding as well.

[66] THE NISSAN NV200 LONDON TAXI. (2019, May 27). Official Europe Newsroom. https://europe.nissannews.com/en-GB/releases/release-95330-the-nissan-nv200-london-taxi?

T.1.2 Questions

Participants had the following questions about entering the vehicle:[67]

a) **Initiation** - Would it be clear how we open the door and initiate the ride?
b) **Waiting** - Will sufficient time be provided for me to approach the vehicle at its pickup point and to board the vehicle if I am slower to board than the average population? How much time will be allotted?
c) **Sensing Passengers** - Will the vehicle sense when the rider is ready to depart, and will it have checks to make sure that the ride does not initiate without all desired members in the vehicle? Parents were particularly nervous that their children may inadvertently begin the ride while they are on the outside trying to bring in strollers, luggage, or other children.
d) **Origination** - Will the AV pick me up where I request it, and will it be able to find me?
e) **Height** - How high off the ground is the vehicle, and what is the means by which the user will be able to climb that step if they need assistance getting over that rise?

T.1.3 Feature Suggestions

- Keep the entrance wide enough to comfortably enter with mobility aids.
- Maintain ample space for turning with a mobility aid inside.
- Choose PU/DOs that are relatively flat and even. Even the smallest incline or decline may influence the safety and/ or perceived safety of a portion of older adults who have a higher-than-average fall risk.

[67] The response to several of these questions show up in the AV operator's Passenger Safety Plan (PSP), but not having read the PSPs, the participants raised these questions, nonetheless.

- Set clear expectations about the walk required from the point of origin to the pickup point well ahead of completing the rider request so that the user can plan their journey or find alternative means of transportation.
- Install handlebars in the entry way for those who need additional support to enter safely.
- Provide ramps when/ where necessary and make them automated if the service is not meant to have an accompanying human attendant to help deploy/ retract the ramp.

T.2 Storage of Aids or Luggage

T.2.1 Needs

Wheelchair and power scooter users would require additional in-vehicle locking mechanisms for safety.[68] For other types of mobility devices, such as rollators, walkers, canes, crutches, strollers; and wheeled luggage, these would require a storage area to carry onboard. Contrary to my initial pre-interview hypothesis that users would prefer to store these in the trunk/ separate compartment, participants expressed rather that - in the complete absence of a human driver - they would prefer to be co-located with their aids as long as the aids were safely secured. For example, a 65-year-old caregiving daughter with a 90-year-old mother asked, "If my mother were to store her walker outside the passenger compartment (e.g., in a trunk), then how would she get it? Who would get it for her?" In fact, most participants using mobility aids preferred to be closer to their aids than not in a driverless vehicle.

[68] This is assuming that their rides would be characterized by remaining in their own wheelchairs/ power scooters rather than transferring out of them and into the vehicle's passenger seats. This type of transfer arrangement is likely to require more space (since the user would take one seat and the mobility device would need to take up a separate space), a greater number of steps, and a higher likelihood of human intervention/ aid. Having said this, exploring these options, user preferences, and feasibility warrants further study.

 [69]

Figure 15 – Wheelchair Accessible AV Retrofit | Photo Credit: Cruise

According to a user experience researcher at a leading AV firm, there are many ways in which a driver is more than simply a person who drives. There are, in fact, many services that they provide tangentially. On the one hand, they enforce rules like preventing riders from drinking alcohol, smoking or doing illegal drugs in the vehicle and can act as an intermediator for interpersonal conflicts. On the other hand, drivers can also act as your personal chauffeur, making your travel experience seamless. This is often done by giving the rider more customized treatment, such as picking them up where they want, listening to where they would like to be dropped off, picking up and dropping off group members along the way, as well as assisting passengers with their luggage, mobility aids, boarding, seating, and exiting the vehicle. Even with complete driving automation, there may still be instances when a user who needs care needs and wants an in-person assistant. In many instances, users may bring someone they already know, but a question for AV fleet operators is whether operators should also have trained staff on hand that could be deployed along with the AV for additional user support when requested.

[69] Cruise [@Cruise] 2022 November 17. Ready for another Origin update? Here's a sneak peak of an early Origin Mobility test, which will improve transportation equity by providing much-needed features for wheelchair users. Twitter. https://twitter.com/Cruise/status/1593294025251258368?s=20.

Admittedly, some AV companies are putting much thought into how their onboard features can be used to bridge some gaps in user experience created by the removal of the driver (including using remote customer communication, and remote vehicle assistance - where a remote operator may nudge the decision-making vehicle to select from a variety of triage options to get out of a bind).[70]

Nevertheless, in the absence of a driver, AV makers not only need to rethink how the user interacts with the user interfaces (e.g., onboard displays and the mobile app ecosystem) and remote representatives, but also need to rethink space, the relative positioning of objects to humans, changes in behaviors within the vehicle, the desired parameter of user activities by the AV fleet operator in-vehicle vs. actual behavior. For example, if there is a mismatch between the space required to travel vs. the space allotted by the vehicle, the user may be forced to deviate from protocol and act in a non-compliant way that also elevates the safety risk of the passengers.

Consider this scenario: riders may be instructed not to bring on board large objects that are not fastly secured while the vehicle is in motion. This would be a sound requirement because an unrestrained object would be hurled at a force 30-60 times its weight in a collision at just 30 miles per hour (30 miles is equivalent to the top speeds permitted for AVs operating in an urban environment for California as of March 2023).[71] When a vehicle collides with another object, say a lamppost or another vehicle, it is stopped abruptly by the impact. Any object inside the vehicle that is not restrained will keep moving at the previous speed of the vehicle in motion because of inertia.[72] "Inertia is

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[70] Phase I Driverless Autonomous Vehicle Deployment Program Advice Letter Status. https://www.cpuc.ca.gov/regulatory-services/licensing/transportation-licensing-and-analysis-branch/autonomous-vehicle-programs/phase-i-driverless-autonomous-vehicle-deployment-program-advice-letter-status.

[71] Speck, S. (2023, March 8). Car Seats: Fast Facts. HowStuffWorks. https://auto.howstuffworks.com/car-driving-safety/safety-regulatory-devices/car-seats.htm.

[72] Ibid.

an object's tendency to keep moving until something else works against this motion."[73] At the same time, studies show that approximately 24% of adults over the age of 65 reported using a mobility device or aid in the past month. One-third of this group used multiple devices.[74]

If a user enters a vehicle with their walker, rollator, or crutches but finds that there is no place to safely store it, they are likely to simply adapt to the environment and place the aid wherever it is convenient - in many cases directly in front of them. This is where it becomes a safety risk for all those in the same passenger space. One interviewee even shared that over time, their rollator break had ceased to work and could not be locked anymore. So where should mobility aids be kept? Falling short of proposing a single design solution, this report will later provide an illustrative sketch of one potential avenue, and a description of the participant voices that provided the logic.

Similarly for parents traveling with babies or children between the ages of 0 to 8 (on average), there are also a set of accompanying spatial requirements. One interview participant had three children, ages two, five, and eight - with one full car seat and two booster seats in a compact car (Mazda 3) and typically two strollers in the trunk. Often, traveling even with a single baby or child can take up additional room where there is a stroller involved. However, traveling with multiple children may mean having a double stroller or more than one onboard the vehicle.

It is also worth noting that strollers come in all different shapes, forms, and dimensions.

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[73] Ibid.

[74] Gell, N. M., Wallace, R. B., LaCroix, A. Z., Mroz, T. M., & Patel, K. V. (2015). Mobility Device Use Among Older Adults and Incidence of Falls and Worry About Falling: Findings From the 2011–2012 National Health and Aging Trends Study. Journal of the American Geriatrics Society, 63(5), 853–859. https://doi.org/10.1111/jgs.13393.

[75]

Figure 16 – Baby stroller types

Some will fold up to a more compact dimension; others will not. Even folded, they are different dimensions - which present challenges if designing standard storage on a mass market vehicle.

Some parents or caregivers frequently adapt and adjust their safety expectations to fit the environment. Others are stricter and will not compromise on safety. Both cases were observed during interview sessions. Several parents - after seeing photo references of AV prototypes - drew parallels to their experiences traveling on transit buses or airport shuttle buses where they would either have their babies in the stroller and lock the wheels or lock the wheels and hold the children - as permitted by regulation. They deemed this an acceptable level of temporary risk. Other parents simply did not tolerate this level of inherent risk without additional safeguards.

[75] Attygalla, T. (2020b, April 27). How to Choose Baby Stroller. Nursery Design Studio. https://www.nurserydesignstudio.com/2016/02/18/how-to-choose-the-best-stroller/.

Figure 17 – Photos of parents traveling with children in buses [76]

An interesting observation is that some parents used car seats and boosters - sometimes even incorrectly - without an understanding of why they were being used at all but rather simply because it was either mandatory or common practice. Conversely, others had an in-depth understanding of the mechanics, good practices, product safety ratings, recommended use instructions of car seats, etc. Between this spectrum of 'self-researched gurus' and 'blind followers', were parents who would in some instances defer to their peers whose parenting abilities they trusted. Where there was transitive trust in pre-vetted products, they would be more willing to try these products upon the referral of their trusted parent peers.

T.2.2 Questions

- Would wheelchair users be able to lock into the driverless vehicle themselves without additional human support if they were traveling alone? Would users of power scooters be able to do the same?

[76] Duggan, K. (2022, September 19). MTA pilots new space for unfolded strollers on seven bus routes | amNewYork. amNewYork. https://www.amny.com/transit/mta-pilots-unfolded-strollers-spaces-buses/
TransLink. (2012, April 23). Strollers on Transit [Video]. YouTube. https://www.youtube.com/watch?v=wZPowV2XdVc
Laughlin, J. (2017b, November 13). Amid parents' pleas, SEPTA is making space for strollers. https://www.inquirer.com. https://www.inquirer.com/philly/business/transportation/philly-mom-parenting-baby-travel-stroller-parents-parent-child-transportation-petition-septa-strollers-20171113.html

- Where would mobility aids be stored and in what manner?
- How would they be secured?
- Would mobility aids be easy to access or would it take significant physical strength/ force to eject them?
    - E.g., Would one need to lift a 15-pound rollator across a safety barrier?
    - E.g., would there be enough maneuvering space to open up a stroller inside the vehicle and place the child/ infant inside it before exiting - especially in case of rain, snow, hail, strong sunlight, etc.?
- Would parents with infants or children need to comply with safety standards applicable to personal motor vehicles or those governing other vehicles like buses?
- Would it be possible and permitted to bring onboard multiple strollers? Would there be a size cap or other restrictions? Where would these be expected and permitted to be kept while the vehicle is in motion?

T.2.3 Feature Suggestions

- Allocate space within the vehicle for users to be able to travel with mobility aids, and strollers.
- Where storage space is created for mobility aids, keep these spaces within reach of the user - unless there is an easy-to-use mechanism by which the user can independently and safely gain access to the aids. Below is an illustration of preferred and permissible reaches (in millimeters) of average adults in a seated position.[77]

[77] Neufert, E. (2019). Architects' Data. John Wiley & Sons.

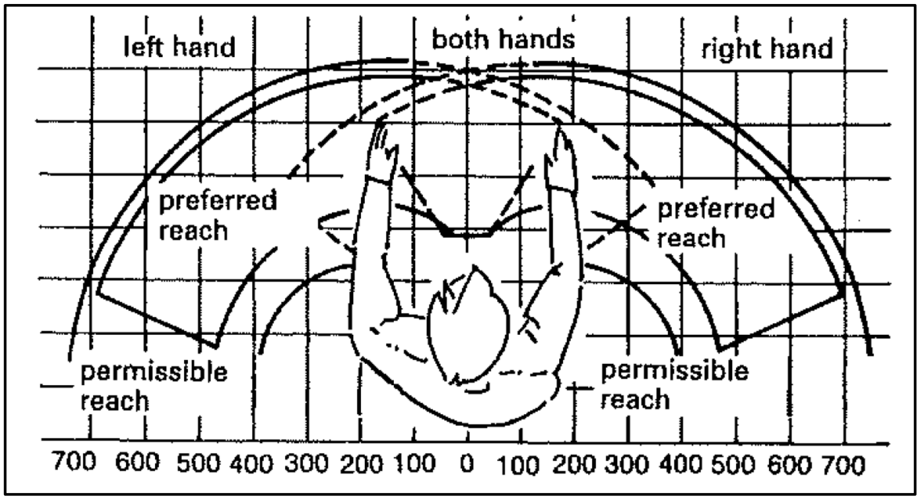
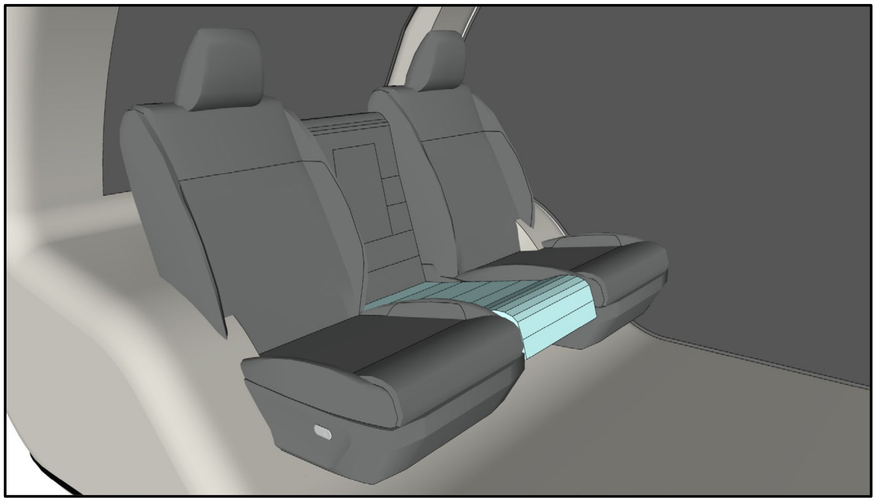


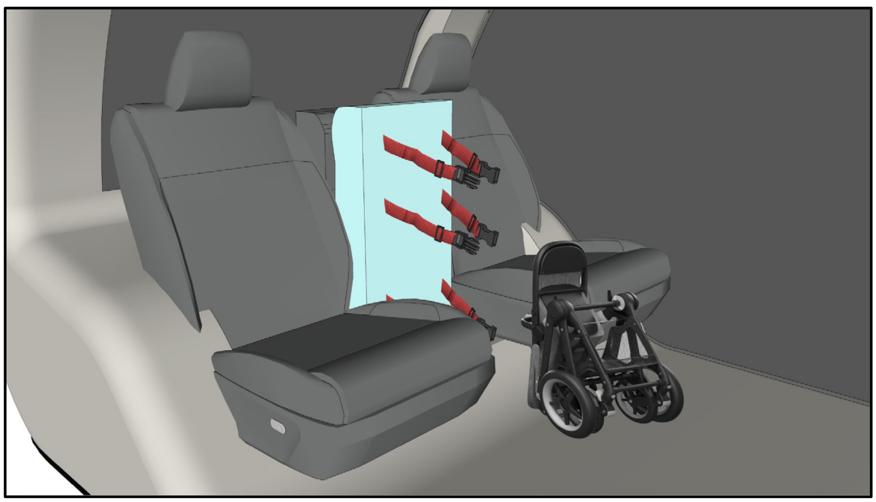
Figure 18 – Neufert's illustration of individual reach

- Where storage is created, make it visible, easy for users to insert and eject items
- Drawing on the collective input of our interview participants on how they would like to access their aids, I proposed below one of several ways in which aids could be stored and harnessed. It is a commonly seen method by which a passenger seat with a mechanical hinge is folded up, locked in place, and the hollowed space is used to park a mobility aid. To protect those opposite to this space, there should be a harnessing mechanism to keep objects from being dislodged. Redundant safeguards, such as a secondary mesh to prevent movement, could also be put in place.[78]
- Improper and unsafe use should be detected and alerted for correction by users.

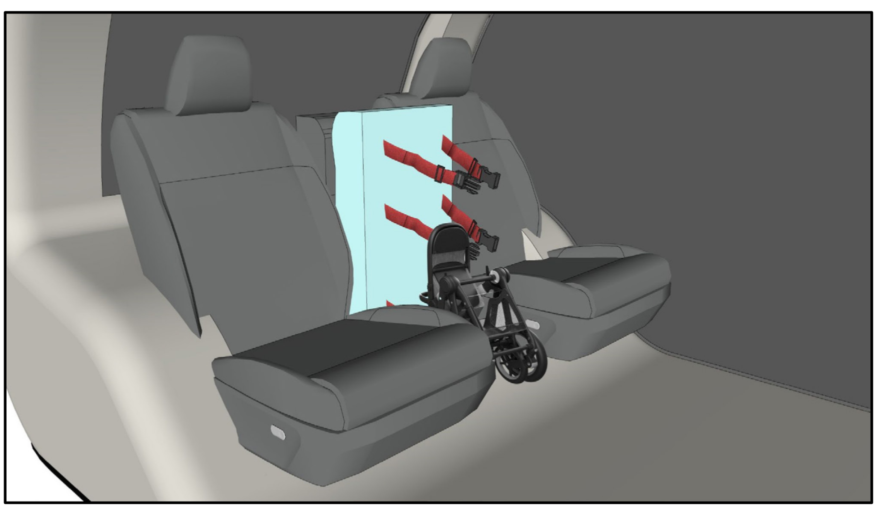
[78] Precedents are drawn from London Black Taxis, Massachusetts transit buses that have folding seats, as well as ways in which dirt bike owners use mesh tailgates or 'tailgate nets' to keep their bikes from moving in the back of their trucks once fastened with ratchet straps.



The middle seat is down and can be used as a middle passenger seat



For storage needs, the middle seat is pulled up, locked in place, and harnesses are exposed. Once done using, the seat can be lowered again (e.g., via another push toward the back seat).



The aid is folded, inserted, and buckled in prior to motion, and then released for redeployment.

Figure 19 – Illustration of potential storage module

T.3 Sitting

T.3.1 Needs

Once mobility aids are placed away, the passenger can get into their seat. A few themes that surfaced repeatedly throughout the interviews were regarding:

- Seating height,
- Posterior/ anterior seat tilt (i.e., what angle the horizontal portion of the seat lies at),
- Seat back recline,
- Seat firmness, and
- Support (e.g., armrest, handlebar).

These together seemed to contribute to the ease vs. unease, discomfort or pain vs. comfort one would experience in acts of sitting and rising. Several opinions converged around the experience that when a seat is too low, it is both painful and difficult to sit or stand up. Participants were in near unison in expressing the need/ desire for arm rests (ideally on both sides of an outer seat) and potentially a handlebar above to supplement the support needed in the standing and sitting process.[79] Three of the other elements above affect seating comfort and the ability/ ease of getting out of a seat. Some participants expressed that slight posterior seat tilt, seat back recline, and padding to add to comfort during a ride, but that these same elements can also make standing more challenging. Biomechanical studies generally support the insights gathered here, and it is worth briefly discussing some of the mechanics and nuances observed over the years.

[79] Regarding arm rests and handlebars, some opinions were expressed from a first-person perspective, and others were provided as a third-person caregiver for an older care recipient.

What we want to understand are the following three things:

1. How does the human body work to get up from a seat?
2. How do various health conditions pose hindrances to that process?
3. How can design help to mitigate pain points and make the experience more manageable in these cases?

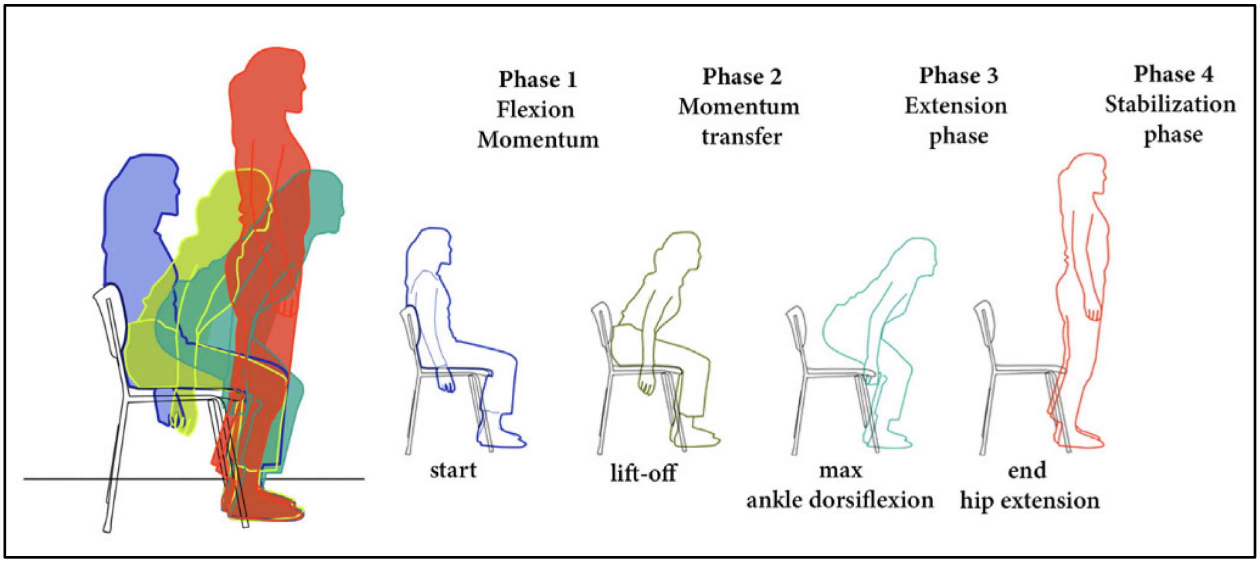


Figure 20 – Four phases of standing illustrated [80]

The most common way to describe the standing process is in **four phases**.[81] In the first phase, we initiate movement to generate forward momentum, but no part of the body has left the chair. Then in the second phase, the buttocks are lifted from the seat and the ankles are bent backwards (dorsiflexed) to prepare for a subsequent push off the ground from the ankles. Here, the feet become the new base of support. In the third phase, called the **'extension phase,'** the hips, knees, and ankles rotate/ open/ extend to raise the body until the hip ceases to extend. In the final 'stabilization phase,' the

[80] van der Kruk, E., Silverman, A. K., Reilly, P., & Bull, A. M. J. (2021). Compensation due to age-related decline in sit-to-stand and sit-to-walk. Journal of Biomechanics, 122, 110411. https://doi.org/10.1016/j.jbiomech.2021.110411
[81] Hughes, M.A., Schenkman, M.L., 1996. Chair rise strategy in the functionally impaired elderly. J. Rehabil. Res. Dev. 33 (4), 409–412.

body is brought upright and there is a contraction of several muscles to stabilize this neutral standing position.[82]

As we age, there are an array of health conditions that can make sitting down and standing up more difficult. The following is meant to be illustrative rather than exhaustive. For those who are more sedentary in their daily routines, reduced blood flow and tightened muscles from long hours of sitting over time can be one reason.[83] When being stuck in a position of hip flexion for too long, blood flow is blocked to the muscles used to carry out and stabilize hip extension.[84] Other reasons might include disease or medical operations that become more common in older age, such as stroke, Parkinson's disease, hip fracture and replacement, arthritis, and joint arthroplasty.[85] For example, according to the CDC, "Among adults aged 65 and older, 50% report ever having been diagnosed with arthritis. Among adults aged 45 to 65 years, 31% report ever having been diagnosed with arthritis."[86] Under these conditions, movements that place pressure on the affected areas, such as the knees or hips can cause discomfort or pain.

What can vehicle makers do to make the sitting/ standing experience more comfortable? Studies show that arm rests help this task significantly. The percentage of older adults unable to stand from a standard-height chair with armrests decreased from 32% to 1% when they were permitted to use the arm rest; the time to stand also decreased from a mean 4.6 seconds to a mean 3.8 seconds.[87] However, it is not entirely about compensating a gap in strength. In one recent experiment published in Nature,

[82] van der Kruk, E., Silverman, A. K., Reilly, P., & Bull, A. M. J. (2021).
[83] Hard to stand up from a chair? Part 1: Why it's hard to get up. https://www.uprighthealth.com/blog/hard-stand-up-from-sitting-chair-part-1
[84] Ibid.
[85] Bohannon, R. W. (2012). Measurement of Sit-to-Stand Among Older Adults. Topics in Geriatric Rehabilitation, 28(1), 11. https://doi.org/10.1097/TGR.0b013e31823415fa.
[86] 4 Facts to Know. (2019, May 17). Centers for Disease Control and Prevention. https://www.cdc.gov/arthritis/communications/features/4things.htm
[87] Bohannon, R. W. (2012).

biomechanics scientists showed that most older aged men used arm rests to stand up despite the fact that they were not weaker than young women who did not use arm rests. They concluded that instead the perception of stability was also an important factor - particularly as the fear of falling increases.[88]

Chair height and positioning matter as well. Lower seats demand greater torque at the knees. On top of this, if the rider has limited knee flexion range, then greater torque is required at the hips as well. [89] A chair rise study run at six different chair heights between 17 to 22 inches showed that about twice as many older adults could successfully stand from a 22-in–high chair as from a 17-in–high chair.[90] [91] Another study entitled "Chair Design Affects How Older Adults Rise from a Chair" pointed out that "increased posterior seat tilt and backrest recline, and perhaps increased seat compressibility cause increased time to rise, increased body motion, and increased self-reported ratings of rise difficulty in both Young and Old groups." [92] As we know, tilt, recline, and compressibility are generally there to enhance comfort during the ride. The ultimate form will need to consider the holistic balance between comfort and useability across user groups.

The condition of misfit between a small child's body and a standard adult-sized seat is more visibly pronounced than for the most older adults. A parent observing their

[88] van der Kruk, E., Strutton, P., Koizia, L. J., Fertleman, M., Reilly, P., & Bull, A. M. J. (2022). Why do older adults stand-up differently to young adults?: Investigation of compensatory movement strategies in sit-to-walk. Npj Aging, 8(1), Article 1. https://doi.org/10.1038/s41514-022-00094-x
[89] Ibid.
[90] Weiner DK, Long R, Hughes MA, Chandler J, Studenski S. When older adults face the chair-rise challenge. A study of chair height availability and height-modified chair-rise performance in the elderly. J Am Geriatr Soc. 1993;41:6-10.
[91] This does not mean that we should automatically opt to raise chair heights to a maximum. In the way of comfort, raising the seat height is likely to have the opposite effect on comfort for children, for example. This decision will ultimately be a balancing act between user groups and characteristics.
[92] Alexander, N. B., Koester, D. J., & Grunawalt, J. A. (1996). Chair Design Affects How Older Adults Rise from a Chair. Journal of the American Geriatrics Society, 44(4), 356–362. https://doi.org/10.1111/j.1532-5415.1996.tb06402.x

daughter seated in the backseat said she looked "highly uncomfortable," "slouched," and "flustered" after being in a seated position over time.[93] With shorter legs, smaller upper and lower trunks, their legs can dangle off the seat without a bend at the knee, and they often cannot sit upright or rest their heads comfortably against the seat.

T.3.2 Questions

- For small children, is there potential for an ergonomic seat design that balances the comfort of an average adult as well as for smaller riders?
- In lieu of this, can child and infant seating be requested and deployed in the AV?
- What is the height of the seat?
- What is the height of the arm rest relative to the seat?
- What is the seat tilt?
- Is the seat surface flat enough to place a child seat on safely?
- Is the backseat recliner adjustable? If not, at what angle is the recline set?
- How cushioned are the seats?
- What is the texture of the interior materials?[94]

T.3.3 Feature Suggestions

Seat positioning is a complex human factors and ergonomics issue for older adults and young children among others as it relates to transportation access, comfort, useability, and safety. As we have seen for those with mobility challenges, fixed design that aims to maximize rider comfort may come at a cost to access (e.g., ease of sitting and standing

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[93] Children were not directly interviewed in this study to minimize risks conventionally associated with qualitative interviews. We relied instead of parents to provide surrogate caregiver opinions.

[94] This question was posed by a mother of a son on the autism spectrum who would not be able to interact with certain textile surfaces.

up for users with mobility challenges).[95] If possible, designing for adjustability is one way to address misfits that occur when fixing seat design for only one bodily mold. Instead, we might allow the seat tilt, recline, height, and perhaps even belt positioning to meet the physical needs of the passenger in the many shapes and sizes they come by moving along a range spectrum.

T.4 Fastening Self or Dependents

T.4.1 Needs

Three-point seatbelts were designed in 1959 to stop passengers from flying out of their seats in collisions or abrupt stops. A less known fact is that they are designed to distribute the force of impact to the strongest skeletal parts of the body, namely the ribcage and pelvis.[96] Worn properly, seatbelts save tens of thousands of lives a year. Not all bodies, however, are protected equally by this mechanism - most notably, children and infants. The 'misfit' in this instance originates from the fact that the vehicle seat as well as associated safeguards, such as seatbelts and airbags, have always been designed to the proportions of an average adult.

For a baby or a small child, a standard seat is far too wide, deep, and tall to be safe or comfortable. One of the reasons children are 'boosted' is to raise the child's torso to the height of the seatbelt. If the child is not raised, often what occurs is that the shoulder strap is placed proximate to the child's neck, face, or throat - acting as a slicing hazard. The National Highway Traffic Safety Administration (NHTSA) in fact "estimates that

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[95] From an implementation standpoint, however, the manufacturer may choose to limit adjustability - for the sake of simplicity and to right size soft and hard costs. Some interviewees - particularly those under the age of 65 - shared that they lower their expectation of comfort when riding in shared transit vehicles as well as for shorter rides as opposed to for longer rides.

[96] Speck, S. (2023, March 8). Car Seats: Fast Facts. HowStuffWorks. https://auto.howstuffworks.com/car-driving-safety/safety-regulatory-devices/car-seats.htm

car seats reduce the risk of fatal injury by 71% for infants (younger than 1 year old) and by 54% for toddlers (1 to 4 years old) in passenger cars."[97] Knowing what we know, the salient question is 'is it safe or practical for a child under the age of 8 to travel inside a vehicle without a child/ infant seat or equivalent device?'

At first glance, the answer may seem like a resounding no. But at closer examination, children under this age have been traveling without a car seat or even as much as a seatbelt in school buses and public transit buses for decades all around the country.

In fact, interview participants were divided on whether they would need a child seat/ infant seat or booster equivalent when riding an on-demand shared AV. A greater number of participants took it as a given that infants and children would need to be placed in seating arrangements mandated by law[98] and commented that it would be onerous/ impractical to carry their own child seat when making on-demand trips in an AV. This segment of parents asked questions such as:

- Would it be an option to request a car seat when calling the AV?
- Do these vehicles have LATCH (**L**ower **A**nchors and **T**ethers for **C**hildren) systems in place to be able to secure child seats to the base of the seat?[99]

[97] Child Restraint - Injury Facts. (2022, April 12). Injury Facts. https://injuryfacts.nsc.org/motor-vehicle/occupant-protection/child-restraint/

[98] Commonwealth of Massachusetts. Car seat laws in Massachusetts. Mass.gov. https://www.mass.gov/service-details/car-seat-laws-in-massachusetts

[99] Federal regulations (FMVSS 213 and 225) made it the law for most (not all) cars to have the Lower Anchors and Tethers for CHildren system (LATCH) after September 1st, 2002.
Baures, L. (2018b, April 10). Not All LATCH Systems Are Equal. Trusted Auto Professionals. https://tap.fremontmotors.com/not-all-latch-systems-are-equal/

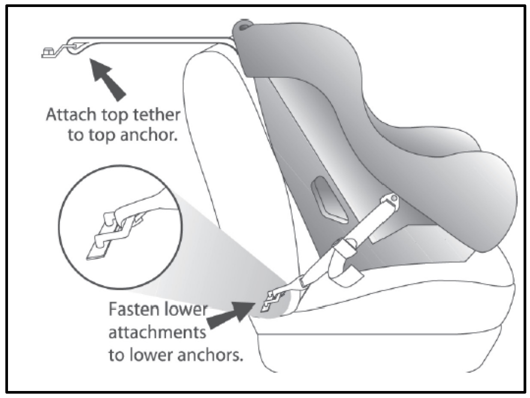

Figure 21 – Illustration of LATCH system | Credit: NY Department of Health

- Will seatbelts be long enough to support a European belt path securement of infant seats? (This is where the shoulder strap is used in addition to the waist strap and therefore needs the pull of the entire length of the belt. Some seatbelts are not long enough to support the European belt path even at full extension)

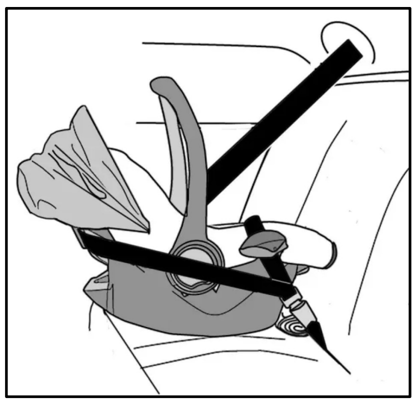
[100]

Figure 22 – Illustration of European Belt Path

- Where is the location of side airbags in the AV in relation to my child or infant and if they are dangerous to children or babies, can I position my baby in a middle seat?
- Will seats be flat enough to install a child/ infant seat properly?

[100] What CPSTs, Caregivers Should Know About European Belt Routing – Safe Ride News. (2014, November 15). https://www.saferidenews.com/2014/11/what-cpsts-caregivers-should-know-about-european-belt-routing/

- Will I still be able to have an infant seat placed to face backwards in an orientation-agnostic AVs (i.e., AVs that are able to change driving directions without turning)?

One observation made was that most full child seats have a 'base' and a 'carrier,' where the base is left attached to the LATCH and typically not removed. This means that totting a carrier would not be the only inconvenience for using an on-demand vehicle with a child/ infant.

By contrast, a second group of parents drew parallels between the shared AV and public transit buses. They said that they could be okay having their child in a standard seat while simply locking the stroller in place for short distance intra-city travel at low speeds. Whether a 'camper style' (format shown in previous chapters) AV is closer to a PMV or a bus is beyond the analysis scope of this study.[101] However, the mere fact that parents are uncertain about which vehicle form should be their safety reference point should give regulators cause to clarify precisely which category of FMVSS regulation/ guideline these new form factor vehicles should be governed when it comes to child safety.

NHTSA's "Occupant Protection for Vehicles with Automated Driving Systems" (signed March 2022) does not speak to where child restraints/ child seats are required for AVs. Instead, it only says that child seats should not be placed in driver's seats (when driving controls are present); that AVs should stop moving if a child were to enter a driver's seat; and points to a testing procedure (FMVSS 225) that talks about child

[101] From a weight class standpoint, current on-demand shared AV prototypes are closer in weight class and size to vans than a much larger, heavier bus.

restraints in the context of shuttles and other vehicle formats.[102] Since each of the states look to federal standards and guidance on these matters, additional clarification is needed on how children and infants should travel in these brand new vehicle formats and how they can effectively be protected.

For many adults, the problem of buckling in has less to do with misfitting and more often to do with inconvenience or discomfort. Frequently, passengers and drivers alike are found not wearing seatbelts if the buckles or belts are difficult to find or reach. Others place the shoulder strap behind their back, significantly reducing the safety benefits of the three-point system.[103] While it may be challenging to alter behavior for all, a few design interventions that can help include:

- Providing sufficient interior lighting to show belt and buckle before departure - even when the door is closed. Several older adult interviewees expressed that with cataracts, macular degeneration or similar seeing challenges, lighting is an important element for interior navigation and enhances safety, convenience and mental assurance,
- Marking both the belt and buckle in a way that perhaps provides higher visibility (e.g., by using highly visible colors while avoiding colors that blend in with the seats or green and red for those with color blindness and partial color blindness), and
- Sensor-based reminders to strap in before departing with additional reminders if passengers are not using or misusing seatbelts.

[102] NHTSA Finalizes First Occupant Protection Safety Standards for Vehicles Without Driving Controls. (2022, March 10). NHTSA. https://www.nhtsa.gov/press-releases/nhtsa-finalizes-first-occupant-protection-safety-standards-vehicles-without-driving.

[103] Spiral Design Studio (www.spiraldesign.com). The History of Seatbelts. Transfinder. https://www.transfinder.com/resources/the-history-of-seatbelts

Finally, for children, if the deployment of full car seats from AV depots is infeasible, then could there still be other compensating measures that could enhance their travel safety? Two main avenues seem available at a high level:

1) Existing alternatives that allow AV companies not to "reinvent the wheel" so to speak. This may include the use of products commonly aimed for air travel or journeys involving rental vehicle. For infants, there are harnesses that strap the baby toward the stomach of the parent, and for children, there are purpose-built child safety vests that lower the seat belt to the child's torso rather than offering a boost to meet the height of the standard seatbelt.[104]

Figure 23 – Examples of off-the-shelf child safety mechanisms

A second pathway may lie in:

2) Designing custom adjustment seat features that can accommodate smaller frames. That is, the seat and/ or seatbelt could be made adjustable to reduce and compress the riding area for smaller passengers.

With customization (Option 2), the AV maker can take control of riding comfort as well as safety, which it otherwise would not be able to do. With existing alternatives (Option 1), the AV maker is able to leverage industry standard approved products

[104] Note that these products are cited as illustrations of existing car seat alternatives. In no way is it meant to provide an endorsement - as the vetting of vendors or products lie far beyond the scope of this project. Independent due diligence is advised. From left: Primo LapBaby Infant Seating Aid, Ride Safer Travel Vest.

quickly and at no additional design expense, but is unable to control the user experience. Both options nonetheless reduce the level of planning and carrying load caregivers need to assume (thereby reducing user friction), and concurrently enhance the level of user protection (compared to the inherent risk of riding with no safeguards).

T.4.2 Questions

- Will AVs be designed and deployed with the safety of children and infants in mind?
- If so, would it be an option to request a car seat or infant seat when calling the AV?
- Will the seats support the recommended manufacturing installation method?
- Will seatbelts be long enough to support a European belt path for infant seats?
- Is it operationally possible that the AV may change its driving orientation mid ride, and will that impact the safety of an infant facing the back - as recommended by NHTSA?
- If not, will compensating safeguards be provided to the rider - knowing that standard seat belts are unsafe for children typically under the age of 8?
- Else, will it be incumbent on the rider to bring their own compensating safeguards?
- If so, will the AV be equipped with LATCH systems in each seat that is now standard for the vast majority of private motor vehicles for child protection?
- Will it be possible to travel with multiple children (e.g., 2 or 3) and receive the same degree of safety protection for each?
- For adults, will the vehicle interior have sufficient lighting for safe interior navigation by those with degraded vision?
- Will the system detect and remind users to wear seat belts properly prior to the ride?

T.4.3 Suggestions

- For NHTSA and other standard organizations that govern vehicle safety (e.g., ISO), provide straightforward and clear standards and guidance on what child safety measures are required for AVs.
- For permitting authorities (e.g., the California DMV and California Public Utilities Commission and bodies that oversee equivalent functions in other states), require children and infant safety to be shown in the currently required Passenger Safety Plans (PSPs).
- For AV makers, ensure a level of passenger safety equivalent to that required for private motor vehicles for smaller than average riders. As described above, this might be achieved by leveraging existing products on the market or via additional vehicle customization. If conventional car seats/ infant seats are the chosen method, ensure that each seat has a LATCH system and that seat dimensions/ positioning allows for manufacturing recommended installation.
- Provide appropriate illumination inside the vehicle and key safety and operational features for users with seeing impairment.

T.5 Initiating Journey

T.5.1 Needs

Once passengers are fastened in, the vehicle can depart. Even though interview participants did not find 'trip initiation' as a significant obstacle, one parent interviewee asked a question from a place of concern.

T.5.2 Questions

- If a parent were placing a toddler or child in the AV, and perhaps doing something else outside of the vehicle (e.g., bringing another child, folding a stroller or bringing luggage) are there any scenarios in which the child could initiate the ride without an adult on board?
- And if so, how promptly could the situation be resolved?

T.5.3 Feature Suggestions

- Mitigate the risk of dependents initiating rides without parental accompaniment (e.g., by adding an additional layer of authorization by mobile interface if requested, or by creating sensor-based detection use cases that trigger additional confirmation before starting the ride).

T.6 Course Correction + Trip Chaining

T.6.1 Needs

For route correction and trip chaining, interview participants talked about needs that they would similarly have to manually driven TNC[105] rides as well - but in the context of not having a driver to convey their requests in real time. Participants raised four (4) conceivable scenarios where a route adjustment could be needed.

The first was in the event of a medical emergency in the middle of the ride. Participants noted that when someone takes a fall or is having difficulty coordinating action or communicating verbally (e.g., in the event of a heart attack or stroke), it is important to have emergency buttons located lower to the floor and also not to rely entirely on verbal confirmations. If a rider urgently needs medical attention and to be transported while

[105] Transportation Network Companies (TNCs) are platform ride providers like Uber and Lyft.

in a shared ride, the AV will quickly need to re-prioritize the trip, re-route to the nearest ER facility, all the while notifying EMS with key information, and potentially even giving other shared riders the option to offboard or to follow and complete their ride from the emergency drop-off point. Both Waymo and Cruise have protocols to call 911 via remote assistants and to coordinate with firefighters or law enforcement in their Passenger Safety Plan documents submitted to state regulators.[106] In other user distress cases that fall below the threshold of requiring emergency medical help or faster human attention, the passenger may simply wish to communicate with bystanders outside of the AV for assistance via speaker or by opening the doors.

The next scenario is setting a destination, such as a restaurant, an urgent care clinic, or grocery store, and arriving at the conclusion of the trip only to realize that the location is closed (e.g., for a reason unannounced on Google or their webpage). Assuming that the platform is able to accommodate the rider to their next alternative destination (i.e., if the next set of shared trips are not fully booked), will the AV be able to wait while the rider searches for an alternative restaurant, clinic or grocery location or perhaps assist the search through its onboard user interface? Is this a common enough occurrence to create a use case around - e.g., by asking at the end of the trip if there were any issues, such as locations being inaccessible due to closure, exit conditions or the environment being too hostile to exit immediately?

Forgetting an item at home is the next scenario. Typically, a single destination trip is set A to B. A multi destination trip is set, for example, from A to B to C to D. However, when someone forgets their eyewear, medication, documents or referral for an

[106] Phase I Driverless Autonomous Vehicle Deployment Program Advice Letter Status. https://www.cpuc.ca.gov/regulatory-services/licensing/transportation-licensing-and-analysis-branch/autonomous-vehicle-programs/phase-i-driverless-autonomous-vehicle-deployment-program-advice-letter-status.

appointment, hearing aid, etc., the user may wish the trip to become A → midway to B → back to A upon realizing the forgotten item → ultimately to B. Assuming the particular ride is not shared/ pooled, would the system be able to field this request in a timely and cost-effective way (even if it involved remote human assistance, and adding a marginal cost for re-routing)?

Trip chaining is the last scenario interview participants brought up. Consider the following case. A retired grandmother, Pam, who is no longer able to drive but wants to help drop off her grandkids to two separate schools in the morning trip chains from home → school 1 → school 2 → back home. At each school, Pam wants to walk her grandkid to the entrance and wait to see them get in safely before heading to the next destination. Will the vehicle accommodate a temporary exit and re-entry in a stationary position during the chained trip (assuming that the ride is not pooled with other parties)?

T.6.2 Questions

- In the absence of a human operator in the vehicle, will the AV be able to sense anomalous situations of apparent distress and medical emergency by the rider, particularly in scenarios where the subject is unable to send or voice a distress call by themselves - and take prompt action?
- Are emergency buttons located within reach of a fallen person - or are they situated only to be reached from a seated position?
- In the event of a medical emergency, is the protocol to have EMS come to the AV or the AV to transport the passenger to the nearest medical site?
- Can the AV accommodate a pause in rides between a trip chained route - perhaps even when passengers have temporarily exited the vehicle (e.g., to pause the ride on the mobile app, get a dependent to the door of the destination, and re-enter

the vehicle before resuming the trip)? Are there liabilities and risks that prevent the fleet operator from doing so, and can these be navigated?

- Are there other common scenarios of error correction that would perhaps have been easier with a human driver onboard for which an AV service would want to create some pre-planned workflows and user prompts/ interactions ready?

T.6.3 Feature Suggestions

- In the absence of a human operator to monitor the vehicle cabin, create normal baselines and detection use cases for perceived passenger distress and emergency scenarios, and train remote operators receiving alerts to accurately assess and respond to passenger needs. Use cases may include falls, heart attacks, strokes, seizures, respiratory distress, loss of consciousness, among others, and some may appear indistinguishable from a resting state.
- Consider the user's ability to signal distress and call for help in a compromised scenario where the user may have fallen to the ground and need help to take action (e.g., such as automatically rerouting to the nearest ER, or allowing for doors to open to call for nearby assistance, or pressing a button to speak with remote assistance if the user remains verbal). Ready-made contingency plans based on pre-defined scenarios/ parameters and actions will reduce reaction time in emergencies.
- Gather feedback and input from users on features that would be useful during chained trips.

T.7 Riding

T.7.1 Needs

This is the moment in the journey where the passenger has initiated all boarding sequences and simply can sit back and ride. In interview conversations, participants shared views on topics relating to information display, general troubleshooting, environment control, and troubleshooting in moments of operational failure.

Information Display - Riding a driverless vehicle can be quite an adjustment for those used to the human-driven status quo. Studies have shown that older adults - more than younger cohorts - want more information on what is going on with driverless systems even as the ride is taking place.[107] In one study, researchers found that participants wanted regular updates on things like speed and how much time is left as well as the vehicle to tell them, for example, that it is aware of the foggy weather and is ready to take appropriate precautions.[108] In my interviews, participants similarly echoed the sentiment of wanting to receive real time updates visually and by sound, including current location, destination information, time to arrival, battery health, and the like.

General Troubleshooting - This could include asking questions, correcting errors (including routing errors), asking for special accommodations, calling for help in dangerous scenarios (e.g., when approached by a hostile actor), or even providing user feedback and feature suggestions to enhance rider experience. Not all troubleshooting or error correction need involve a remote human operator. For common errors, interactions, and instructions, these can be pre-recorded, programmed, or aided by artificial intelligence-aided responses.

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[107] Eveleth, Rose. "Stop Saying Driverless Cars Will Help Old People." *Wired*. December 15, 2019. Accessed May 9, 2022. https://www.wired.com/story/stop-saying-driverless-cars-will-help-old-people/.
[108] Li, Shuo, Phil Blythe, Weihong Guo, Anil Namdeo, Simon Edwards, Paul Goodman, and Graeme Hill. "Evaluation of the Effects of Age-Friendly Human-Machine Interfaces on the Driver's Takeover Performance in Highly Automated Vehicles." Transportation Research Part F: Traffic Psychology and Behaviour 67 (November 1, 2019): 78–100. https://doi.org/10.1016/j.trf.2019.10.009. Note that this study was done on cars with Advanced Driving Assistance Systems (ADAS) and not 'highly automated' L4, L5 vehicles.

Environment Control - When asked what element users would like control over, participants talked about:

- Volume control (for the hearing impaired),
- User interface text size where possible,
- Temperature control to the extent is does not significantly impede on other user's riding experiences (e.g., the way one may adjust overhead fans on a plane),
- Exposure to sunlight - particularly those who need protection from the sun as well as babies who need shade for rest.

Operational Failure - With incremental increases in permitted vehicles operating in urban areas and expanded hours, there have been a growing number of stalled autonomous vehicles in deployed areas, including San Francisco (CA), Phoenix (AZ), Chandler (AZ), among others. Some unresolved scenarios may even require passengers to end the ride and exit the vehicle.

The question is what the standard operating procedure in these cases, and whether it can create situations in which trips of vulnerable users are seriously disrupted (e.g., those with higher fall risks, medical conditions that could induce pain, distress or more serious harm from prolonged periods of sitting, standing, the exposure to unfamiliar settings, raised anxiety, or alternatively being left stranded in unsafe areas raising the risk of assault or other crimes or hostile outside elements, etc.).

Imagine a scenario in which an 85-year-old passenger with osteoporosis, osteoarthritis, past fall incidents, and recent hip replacement using a walker needs to exit the vehicle stalled in the middle of an unfamiliar intersection. Assuming that operational failures will happen (even if they decrease in probability with improvements in technology), a clear protocol with close user communication will be needed to mitigate the inherent risks of more vulnerable populations facing unanticipated stops of vehicle exits.

T.7.2 Questions

- What is the standard operating procedure (SOP) for resolving a stalled trip for the user? To be clear, this is not a question about what the SOP is to reconnect or collect the vehicle, but rather one relating to the contingency plan for enabling the passenger to complete their trip safely and in a reasonably timely manner.
- As a corollary, within a given operational design domain (ODD), what are target mean response times? These could be measured in MTTA (mean time to acknowledge) a stalled event, MTTR (mean time to respond, recover, repair, or resolve).

T.7.3 Feature Suggestions

- Service level agreements and response times should be clear - if not to the customer directly, at least internally to the service provider as to set a standard of care.
- In responding to stalled vehicles and helping transition passengers to another vehicle or mode of transportation, include a step in the SOP to ask whether the passenger(s) have special needs or health conditions that require additional care.
- Train response staff to assist users safely and with respect (e.g., older adults, users with mobility aids, parents with children, persons with disabilities).
- Make sure that no one is left feeling unsafe in the waiting or vehicle transfer periods, and provide persistent communication.

- For situational awareness while riding, provide periodic updates on what the vehicle is sensing, planning, and doing, as well as any user warnings or instructions by audio and visual means.

T.8 Getting up

T.8.1 Needs

For older adult interviewees with mobility challenges, they valued being able to get up easily, comfortably, and safely. When it comes to ease, many of the same principles we saw in the T.3 "Sitting" section apply. To recap, when users are able to use arm rests to stand, they are much more likely to be able to stand quicker.[109] This helps move from phase 2 to 3 in a typically standing process as shown in the diagram below. Additionally, the placement of a handlebar that users can pull on in phase 3 (extension) and hold or lean on in phase 4 (stabilization) adds to ease and safety. On average, studies show that orthostatic hypotension (a sudden drop in blood pressure when standing) becomes more common with age, and is positively correlated with falls.[110] A handlebar can act as a stabilization aid during transitioning from phase 4 to walking and help mitigate some of these risks. See the London Black Cab example below as a reference. Also, higher seats demand less torque at the knees. Where the user has limited knee flexion range, higher seats help reduce torque required at the hip as well.[111]

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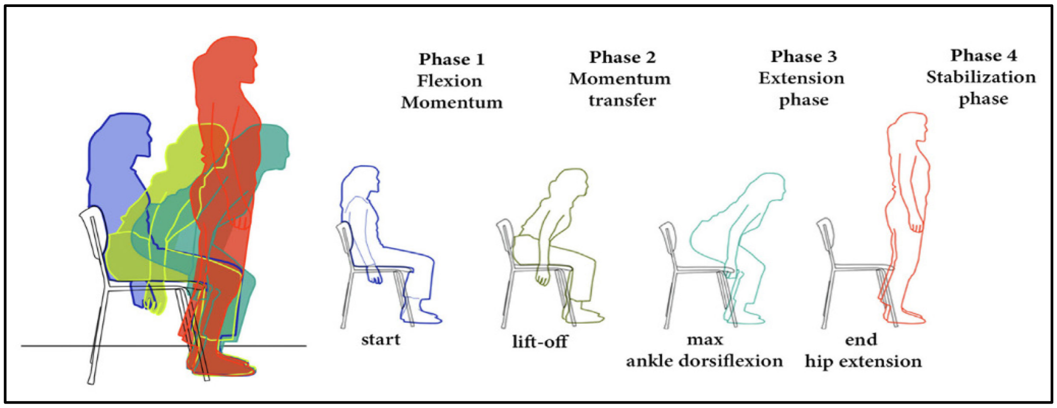
[109] Bohannon, R. W. (2012).

[110] Mol, Arjen, Phuong Thanh Silvie Bui Hoang, Sifat Sharmin, Esmee M. Reijnierse, Richard J. A. van Wezel, Carel G. M. Meskers, and Andrea B. Maier. "Orthostatic Hypotension and Falls in Older Adults: A Systematic Review and Meta-Analysis." Journal of the American Medical Directors Association 20, no. 5 (May 2019): 589-597.e5. https://doi.org/10.1016/j.jamda.2018.11.003.

[111] Ibid.



112

Figure 24 – Four Phases of Standing Illustration


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Figure 25 – London Black Taxi | Photo credit: Nissan

As mentioned in section T.3, smaller posterior seat tilt, backrest recline, and less seat compressibility was shown to be correlated with quicker time to stand, less body motion, and less self-reported ratings of difficulty in standing.[114] At the same time, each of these elements (tilt, recline, compressibility) typically contribute to user comfort during a ride. While I proposed designing user-adjustable seat features earlier in section T.3, for fixed

[112] van der Kruk, E., Silverman, A. K., Reilly, P., & Bull, A. M. J. (2021). Compensation due to age-related decline in sit-to-stand and sit-to-walk. Journal of Biomechanics, 122, 110411. https://doi.org/10.1016/j.jbiomech.2021.110411.
[113] The Nissan NV200 London Taxi. (2019, May 27). Official Europe Newsroom. https://europe.nissannews.com/en-GB/releases/release-95330-the-nissan-nv200-london-taxi?
[114] Alexander, N. B., Koester, D. J., & Grunawalt, J. A. (1996). Chair Design Affects How Older Adults Rise from a Chair. Journal of the American Geriatrics Society, 44(4), 356–362. https://doi.org/10.1111/j.1532-5415.1996.tb06402.x

seats, I suggest user testing across a range of ages and mobility conditions gathering both quantitative and qualitative feedback on useability and comfort.

Finally, some interviewees with vision impairment (brought on by macular degeneration and cataracts in their cases), valued lighting their path before and while exiting the vehicle for safety.

T.8.2 Questions

- Do armrests extend far out enough near the end of the seat so that they can be used to support the process of standing up?
- Is each seat within reach of an arm rest?
- Are handlebars located where users can utilize them for standing up, sitting down, as well as getting and out of the vehicle?
- Are seats designed and placed in a way that does not add additional challenges to standing up by older adults with mobility difficulties?
- Can the vehicle illuminate an exit path for the user upon arriving at the destination?

T.8.3 Feature Suggestions

- To provide additional support to standing, place arm rests
  a) Within reach of each of the seats
  b) To extend far enough to the edge of the seat so that I can be used for support
  c) At a height that is well suited for support
- Place visible handlebars in high contrast colors by each of the exits, and additionally as needed.

- Illuminate the floors or the cabin once the journey is complete and the user needs to exit in dark environments/ contexts.

T.9 Gathering Aids or Luggage

T.9.1 Needs

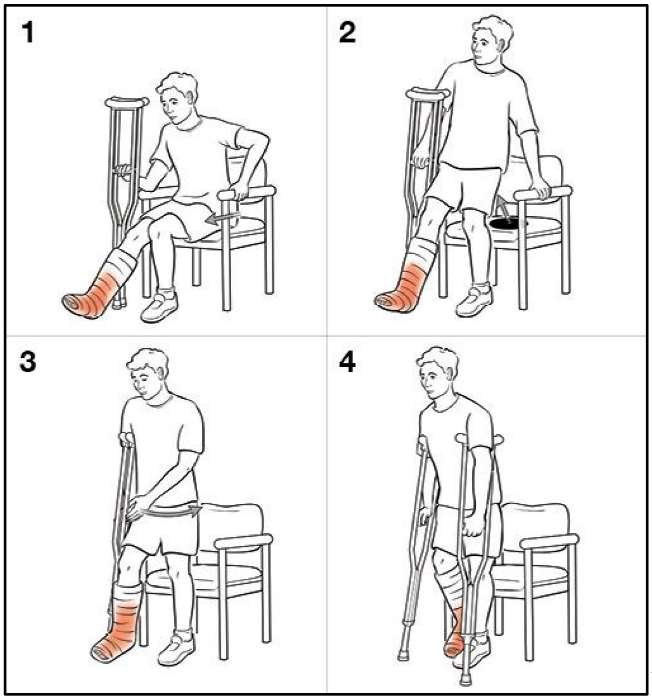
Whatever storage mechanism the vehicle has, it should enable the user to easily retrieve and redeploy their mobility aid/ device so that the user is able to continue the remainder of their journey. Interview participants shared that - in a driverless vehicle - this means that:

- Travel aids should be proximate to where you are sitting,
- Releasing the aid from any harness/ restraint system should be easy for the user,
- The user should not have to lift their aid (e.g., a rollator) over any sizeable barrier (e.g., over a fixed guard rail),
- The user should not have to reach overhead or bend down to the floor to retrieve their aid - as this would present range of motion challenges to many of these users,
- Once the user gathers and deploys their aid, they should be able to maneuver a path to egress from that position (e.g., make any necessary turns to forward face the right exit[115] from the deployment point),

Additionally, creating a seamless connection between T.8 (Getting Up) and T.9 (Gathering Aids or Luggage) is important for those who have a greater reliance on their mobility aids. If one is able to retrieve and deploy/ position their mobility aid from their seated position and use it for stabilization, that would be even more ideal. A passenger relying on crutches for walking support, for example, would typically have both crutches in hand on the side of the bad/ injured leg before standing to be able to

[115] This is assuming that the passenger will connect to the curb in the far-right lane in an American setting.

reposition both under each arm once standing. Sometimes, they may even use the mid-section of the crutch to push upon while standing.



[116]

Figure 26 – How People in Crutches Typically Stand Up

For a rollator or walker user, they would ideally want to have their device directly in front of them once they stand. Storage proximity helps these contexts. If users are able to reach over to their side, release, and grab their aids (or slide them out), this will help users exit safer than in scenarios where they would need to travel extra distance to get to the aid.

Older adult participants using mobility aids similarly indicated that for luggage, such as bags or groceries, that they would value having easy access to them in the absence of a human driver or helper. They did not like the idea of retrieving items from the trunk/ rear of the vehicle as a separate step in the absence of a driver that could help. If the AV was double parked in a travel lane, this would mean that the user would need to

[116] Step-by-Step: Standing with Crutches (Non-Weight Bearing). Saint Luke's Health System. https://www.saintlukeskc.org/health-library/step-step-standing-crutches-non-weight-bearing#.

retrieve items while in the travel lane, cross over to curb-adjacent lane (where there may be roadside obstructions or oncoming bikes/ micro mobility vehicles), and then climb the curb onto the sidewalk. If the AV parked curb-adjacently, then they would perhaps exit directly onto the sidewalk, but then have to descend back onto the street to access the trunk and climb the curb once again. These types of movements add greater challenges to the overall trip. Participants with mobility aids therefore seemed to favor closeness to luggage to the extent that is safe.

T.9.2 Questions

- How can designers of driverless vehicle interiors best enable users of mobility aids to retrieve and set up their aids for the next leg of their journey?
- Where should storage units or areas be located in relation to each of the passenger seats?
- Would we be able to co-locate luggage with passengers while also keeping passengers safe in motion?
- How can harnesses be designed for the easy release of aids without compromising on safety?
- Can all this be achieved without putting the user through a steep learning curve?

T.9.3 Feature Suggestions

- A release mechanism that is intuitive, familiar, and not laborious is important in T.9 - gathering aids or luggage.
- From a redeployment position, the user should have access to a relatively straightforward path to exiting the vehicle.
- The illustrative prototype concept previously shown in section T.2.3 is able to store crutches, foldable rollators, walkers, strollers, and the like. It utilizes a fastex

buckle system with adjustable straps that ought to be familiar to most users. However, if there are mechanisms and prototypes that further enhance the ease of use while preserving passenger safety, then that should be the path forward.

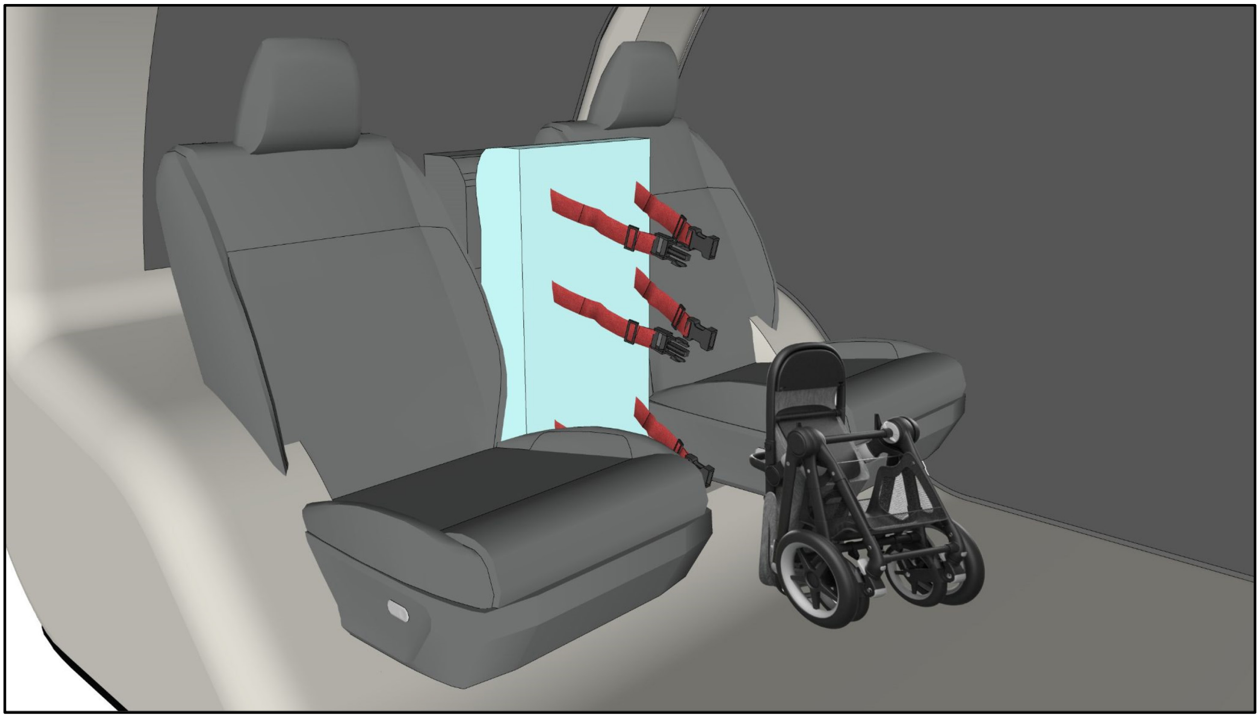


Figure 27 – Illustration of potential storage module

T.10 Exit

T.10.1 Needs

Vehicle exit is a critical element that shapes the experience users take away from the entire trip. Providing a pleasant and safe transition out, therefore is very important both from within the vehicle as well as in connecting to the drop-off point. Within the vehicle, interviewees shared that placing a handlebar at the door to help with exit would be necessary for stabilization as well as to mitigate fall risk. As before, ramp connectivity onto the sidewalk (or directly in connection to a curb cut in lieu of direct sidewalk egress) would be required for users of wheelchairs, power scooters, rollators, walkers, and useful for users of strollers and other mobility aids to continue on.

Conversely, drop-offs in the middle of a travel lane or far from a pedestrian path would inhibit and further disable their journey. Imagine a user of a wheelchair or walker being dropped off in a travel lane with oncoming bikes and scooters at high speeds, subsequently met by narrowly parked cars that our users are unable to circumvent. Finally, a curb cut is nowhere to be seen. This would in effect force the user to move parallel to the street exposed to cars and other modes until they are able to find an opening to climb the sidewalk. This scenario is neither pleasant nor safe.

Drop-offs close to pedestrian paths are important for the safety of children as well. One mother interviewee worried that if they were holding a toddler in one arm with a folded stroller in the other, their 6-year-old might dash out the vehicle the moment the doors opened without looking to see if there were bikes or other vehicles.

It is only through repeated demonstrations of safe and enjoyable drop-offs that on-demand AV services will be able to build trust with its users.

T.10.2 Questions

- In scenarios where it is unsafe to exit (e.g., being threatened by an attacker or in front of a construction area), can the user lock the vehicle and request that they are transported away from that environment?
- How about in avoiding other hostile environments/ grounds (e.g., disembarking where it is extremely dark, puddled, slippery, heavily sloped or uneven ground, or has oncoming traffic)? Can the user fine tune and reposition the drop-off once the vehicle has come to a stop?

- When the vehicle is stopped and has opened its doors, is there any additional signaling or communication needed with external actors to say that there are passengers exiting?
- Is the AV providing a safe and pleasant drop-off experience for the user, and is the user being enabled to continue and complete their journey from the vehicle?

T.10.3 Feature Suggestions

- Place highly visible handlebars at the side of each exit
- Illuminate the exit path before the doors open (see T.9.1)
- Work closely with cities to learn curb management policies/ rules/ zones, the location of where the curbs are cut, and where drop off is safe and permitted
- For mobility aid users, prioritize drop-offs closer to the pedestrian paths, and enable on-sidewalk ramp connections where requested
- Prepare a set of safety protocols for unsafe and inhospitable exit conditions
- Work with the city to learn where curb cuts are located and

A Review of the Initial Hypotheses

Below is a reflection on four initial hypotheses posed at the proposal stage of this study, and subsequent insights from interviews and analysis.

H1. Respondents would require additional space for their luggage or travel aids, and would not frequently use robotaxi services if they are unable to occupy space additional to their own seats.

Observations from participants:

Results were mixed. In cases where users were traveling with larger devices (e.g., wheelchairs, power scooters, knee scooters, etc.), space additional to a single occupant seat was necessary. For parents traveling with children, there was often diaper bags and other luggage. However, parents often said that they could carry these in their lap. Also, older adults with mobility challenges or mobility aid users commented that they might in fact carry less and less in their journeys due to the labor involved or constraints presented by the mobility aid itself (e.g., users of crutches would typically carry no or minimal loads). The response was also use case dependent. If the trip was for groceries or larger purchases, space would be required. However, these respondents typically did not say that they would need to occupy additional seats or space due to their purchased goods.

H2. Users would want to place their mobility devices in the trunk or a separate compartment from the passenger space.

H3. Users would prefer to fold away or sit apart from all forms of mobility aids due to safety concerns.

Observations from participants:

H2 and H3 turned out largely not to be the case with the exception of two respondents who valued safety above all and did not use mobility aids. For the most part, if there was significant reliance on a mobility aid, participants indicated that they would like to be co-located with their mobility aid for easy access in the absence of a human helper. As we have seen in the section above, this has implications for safety design and balancing the need for proximity with the need to prevent projectile risk of these objects.

H4. Regarding accessibility features - There may be a small number of common requests (e.g., adjustability of font size on display and volume due to the prevalence of visual and hearing impairment with age), but there will also be great heterogeneity in special requests due to differences in health conditions among older adults.

Observations from participants:

For the most part, H4 held true. There were a number of requests common to several older adult users (e.g., arm rests, handlebars, higher seating, some degree of cushioning and back support, and lighting), and requests common to several parents (e.g., the ability to properly install car seats, infotainment options to keep children occupied, a place to keep their strollers), but there were also needs and requests that were unique from user to user. These included a user on the autism spectrum not being able to interact with certain seat textures but rather only textures that he was comfortable with, being able only to communicate through visual images and not through text or voice, or having a combination of seeing and hearing impairment without knowledge of braille (which is quite common among people with multi-sensory impairment).

Though this study has tried to go a step further from equating vehicle accessibility with solely wheelchair accessibility - to broadening our thinking to users of mobility aids - an area of further study remains how 'invisible' or less visible disabilities, such as cognitive or episodic conditions may also be considered and cared for within vehicle design.

4. Chapter Four - Recommendations

Overview

Building on the set of recommendations made in the previous chapter, this section organizes and attributes those recommendations to four (4) different groups listed below, and also makes two (2) public policy proposals to stand up AV consumer-centered institutions at the federal and state levels.

The aforementioned four groups are:

a) Vehicle supply chain actors (including vehicle designers and manufacturers)
b) AV fleet planners and operators
c) Governmental and regulatory entities under their existing regimes - federal, state, local/ tribal
d) Advocacy groups (e.g., AARP, AAA - they represent the drivers of today; do they represent the passengers of tomorrow?)

To gather information about the current regulatory landscape, I spoke with government leaders in California, the state where AV testing is the farthest ahead. Based on with interviews with the National Highway Traffic Safety Administration (NHTSA), the California Public Utilities Commission (CPUC), the California Department of Motor Vehicles (DMV), the San Francisco Municipal Transportation Agency (SFMTA), and several AV makers, there is no one entity that has both a strong accessibility-driven mandate and simultaneously the enforcement authority to demand TNC or AV service providers that they make vehicles accessible to users with disabilities or mobility difficulties (e.g., that commonly accompany old age even without a disability).

In the absence of market incentives to drive age-inclusive design, we need a combination of continued advocacy led by organizations that represent mobility constrained persons, as well as a degree of regulation on enabling traditionally underserved groups to similarly benefit from these tech-driven transportation advances.

Recommendations

1.A. Vehicle designers and manufacturers

Drawing on some of the user touch points highlighted in the previous section, design and build autonomous vehicles in a way that allows for independent use by users with commonly used mobility aids in old age and in early parenthood while offering safety protections for young riders in an equivalent or comparable way it does to adults.

While maintaining efforts to provide wheelchair accessible vehicles (WAVs), do not brush aside other common travel user profiles that use different forms of mobility aids. Continue to engage with organizations and coalitions that represent older adults (e.g., AARP), parents with children (e.g., Safe Kids Coalition), and various organizations that represent persons with physical or cognitive disabilities and incorporate feedback into design. Improving accessibility will simultaneously serve to unlock the market potential for another set of riders who are currently underserved and limited in their transportation mode options.

1.B. AV fleet planners and operators

Work closely with municipal departments who oversee curbs (e.g., chief of streets, new mobility planning, transportation services, parking, etc.) to exchange data on curb regulations, locations, use patterns, availability, etc., in exchange for how you as a fleet operator use these curbs.

With this data, perform pick up and drop offs that meet riders directly on or next to the sidewalk for those who need a direct connection (e.g., wheelchair and rollator users). There are instances where there can be a trade-off between perpendicular proximity to the curb and parallel closeness to the user. Prioritizing which is more important to the user may be a combination of knowing the user needs ahead of time (e.g., whether curb connection is required), and being able to coordinate/ communicate with the user in near real time. The same goes for drop off. Similar to recommendation section 1.A., continue to work with users and coalitions to see what kind of PU/DO features and connections are most meaningful.

My general recommendation for fleet operators - in addition to gathering quality data about curb conditions - is to **prioritize the safe and user-friendly pick-up and drop-off of users with young children, strollers, rollators, walkers,** and the like. Stops made in travel lanes are unsuitable often for the safety and accessibility of these users, and this should be kept in mind.

1.C.1. Federal Entities

The National Highway Traffic Safety Administration (NHTSA) should **provide greater clarity on the standards governing safeguards for children and infants in autonomous vehicles**, specifically to include mention of what vehicles need LATCH

(Lower Anchors and Tethers for Children) systems and **which are exempt, if any**[117], and whether child seats are required in these new autonomous vehicle formats, and which are exempt, if any. If the same rules apply as before under existing vehicle categories and standards, this should be made clear as well.

NHTSA should also commission evidence-based safety studies on a number of new form factor AVs, which include crash tests with dummies that emulate users with mobility aids, infants, and children to demonstrate that these vehicles meet the same standard of safety as what the agency expects of conventional vehicles. NHTSA could do this in public-private collaboration with the Insurance Institute for Highway Safety (which runs crash tests), and the American Association for Retired Persons (which could advise on test parameters), among other groups.

1.C.2. State Entities

Following standardization and guidance around child protections in AVs from NHTSA (which focuses more on manufacturing standards), **states should regulate and enforce** these standards within their borders - e.g., on whether vehicles operating in one's state have required safeguards and continue to maintain them at good operating quality.

When it comes to passenger transportation services (including autonomously driven vehicles), there are often several state entities that have oversight responsibilities. In the State of California where AV passenger rides are perhaps occurring most robustly as of 2023, for example, there is the state Department of Motor Vehicles (DMV), which oversees permitting and licensing. There is also the California Public Utilities

[117] LATCH systems are covered under FMVSS 213 and 225 presently.

Commission (CPUC), which subsequently determines whether a passenger-serving AV operator has a safety plan prepared and provides approval. There is the California Department of Transportation (CalTrans) which oversees infrastructure planning, maintenance, and safety around state highways on which AVs might operate in the future.[118]

Of these entities, the DMV evaluates/ reviews whether the manufacturer's AV technology is at their purported level (e.g., L4), whether it is ready for road testing with a safety driver, whether the safety driver meets the standard and past driving record to be licensed, and when it is appropriate to permit the removal of the safety driver, and when the AV fleet operator can begin charging consumer fares for rides. According to interviews, the DMV does not oversee accessibility, equity preparedness or practices.

The CPUC, on the other hand, establishes guidance on accessibility when approving permit applicants during its Passenger Safety Plan review process.

The Commission authorized the deployment of autonomous vehicle passenger services in November of 2020. In this decision/ rulemaking document, there are a few notable sections that talk about making AV services accessible. Two examples include:

> "...permit holders must describe in their quarterly reports whether and how they have reached out to advocates for accessibility and for disadvantaged, low-income, or underrepresented communities, including the names of specific organizations or individuals so long as those organizations or individuals agree

[118] As of 2023, the operational design domains (ODDs) of operators for fully autonomous rides are typically confined to urban roads, and not highways even though Waymo is permitted to test on highways.

to have their names shared. The permit-holders must describe whether and how they have incorporated the advocates' feedback into their operations."

"The Commission is careful to note that "accessible rides" and "wheelchair accessible" are not interchangeable terms. Accessibility extends beyond wheelchair accessibility: accessible rides and accessible service are inclusive of all people with sensory, cognitive, and physical disabilities."[119]

At a high level, these statements are a good set of guiding principles. However, there needs to be a greater call to action with a degree of granularity in implementation and measurement. When we look at the CPUC's Application Instructions and Requirements for [AV] Permit Holders, there is more specificity, but it seems to stop short at requiring AV companies to provide accessible rides or provide discernable data on service coverage. This section is not aimed to single out California as a problem case. Quite the contrary, California is referenced here rather because the nation as a whole looks to the state as a progressive leader, and therefore, it is likely that other states will follow in the likeness of the first movers. Some examples of where the CPUC talks about accessibility include[120]:

1.C.2.1. "The Passenger Safety Plan must, at minimum, detail how the applicant will… 8. Ensure the safety measures described… are accessible to and apply to

[119] Decision Authorizing Deployment Of Drivered And Driverless Autonomous Vehicle Passenger Service. Decision 20-11-046. Public Utilities Commission Of The State Of California. November 19, 2020. https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M352/K185/352185092.pdf.

[120] "CPUC Autonomous Vehicle (AV) Drivered and Driverless Pilot and Phase I Deployment Programs - Application Instructions And Requirements For Permit Holders" California Public Utilities Commission. October 26, 2021. https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/consumer-protection-and-enforcement-division/documents/tlab/av-programs/cpuc-av-program-applications-guidance-20211026.pdf.

all passengers, including those with limited mobility, vision impairments, or other disabilities."

1.C.2.2. "How will your service accommodate people with disabilities, including people with hearing difficulty, vision difficulty, cognitive difficulty, ambulatory difficulty, self-care difficulty, and independent living difficulty? How will your service accommodate various types of accessibility and mobility equipment, including service animals?"

1.C.2.3. "How do you plan to minimize safety risks in shared rides for passengers of all backgrounds, ages, and abilities?"

1.C.2.4. "How will you ensure passengers exit the vehicle into a safe situation, in both routine and non-routine (e.g., collision, passenger requests early drop-off) exits?"

1.C.2.5. "How have you engaged with the disability community, disability advocates, and other related organizations to design an accessible service? How and to what extent will you continue these engagements?"

1.C.2.6. "How will your service accommodate minors, even if accompanied by an adult?"

1.C.2.7. "How have you engaged with youth and/or their advocates to design a service that is safe for minors?"

In fact, as we review these seven clauses and questions cited above, if state regulators were to seek accountability around just these items, it would address nearly all of the recommendations presented in this paper's Findings and Implications section.

1.C.2.6 and **1.C.2.7.** together would at least invoke the question around whether car seats can be used according to manufacturing instructions in new form factor vehicles. The second question in **1.C.2.2** gets at the heart of this paper, which is 'will mobility equipment users be able to pragmatically use these shared AVs in their everyday lives?' To do **1.C.2.1** effectively with the knowledge that there is a large segment of the population that uses mobility aids, safeguards need to be present to safely store the aids while the vehicle is in motion. For those who cannot climb the curb, the answer to **1.C.2.4** will need to be a combination of direct ramp-to-sidewalk connections or ramp-to-curb-cut drop-offs. Otherwise, users will be left in unsafe scenarios.

Building on some of the CPUC's positive questions and guidance above, my **recommendations** for state entities across the country that regulate AV operations are the following[121]:

1. Make the approval of Passenger Plans contingent on Accessibility Preparedness as well as Safety Readiness (and not simply on safety).
    - This conditionality would convey a strong stance on accessibility at the state level.

2. If #1 is challenging, at minimum, establish a more robust set of criteria and guidance around the AV company providing the same degree of passenger safety for people "of all backgrounds, ages, and abilities" (as captured in **1.C.2.3.** above).
    - This could, for example, be done by using stronger language, such as "the applicant must show a plan and demonstrate…" instead of making the application of the state's guidance discretionary.

[121] These are aimed broadly at all U.S. States are currently or may at some point allow AV testing and operations within their borders.

- Then, the state could include a few key examples, such as children traveling with adults, and users of rollators or wheelchairs, and collect plans.

3. Require quarterly reporting that include both quantitative performance around the operator's initial commitments to accessibility and safety, as well as qualitative feedback received from passengers as well as advocacy groups that they engage - with traceability.

4. Stand up the institutional infrastructure to review and assess good standing on quarterly reports provided by the applicants.
   - As testing/ operating areas grow with a state (e.g., from one city to a dozen), the state will likely not have the personnel power to review all compliance/ violations in a thorough and timely manner.
     Some of this responsibility will need to be shared with regional or local substate entities.
   - Coordination between substate and state bodies on enforcement will be important to keep AV operators accountable.
   - That is, even if cities happen to report on patterned unsafe or discriminatory practices within their borders, they may not have the authority to demand that the company pause operations until patterned issues are fixed or expand accessible rides.

5. Establish escalation and enforcement procedures for actions to take after AV operating approvals are granted in close coordination with substate entities.
   - In the absence of such coordination and defined workflows, the only recourse cities/ towns will have at their disposal may be to issue citations

and tickets for Individual reported infractions without being able to resolve any systemic or patterned problems where they are found.

6. Incorporate the institutional infrastructure (#3) and enforcement coordination (#2) through the course of incremental approvals of expanding the AV operator's operational design domain (ODD) and vehicle numbers.
    - That is, make sure that each incremental approval and maintenance of operating permits are contingent on keeping a good standing against state commitments and state-imposed rules.

1.C.3. Local/ Tribal Entities

1. If the city or town has the authority to regulate operating permits within their own borders, then similar to recommendations made for states, hold the AV operator accountable to requisite accessibility and safety standards for the municipality.

2. If this is not the case, continue to observe and generate reports on AV behavior/ practices, and submit official complaints and regulatory requests for enhancements.

3. Continue to invest in and build coalitions with other substate and advocacy groups. Admittedly, this could be challenging in early years, as there will be a limited number of geographies in each state where active AV services are deployed.

1.D. Advocacy Groups

Because there is no government entity currently dedicated to advocating for age-inclusive and disability-inclusive passenger AV services, advocacy organizations have an even greater role to play. There are a few ways in which advocacy groups can make an impact:

1. Serve as advisors to both AV companies and government bodies regarding the needs, urgency, and aspirations of their members.
2. Build coalitions among groups that have overlapping and mutual members, interests, and objectives when it comes enabling autonomous mobility for its members.
3. As another form of advisory, produce thought leadership on AVs and what changes are needed to meet the needs and desires of their members.
4. Seek accountability both through the government as well as with the AV companies on accessibility and safety - e.g., by making any incremental support to permit applications, ODD or fleet expansion conditional on each company's track record and progress on accessibility and safety.
5. Collaborate with local governments on advocating additional regulatory oversight to the state where needed.

2. Public policy recommendations for regulatory reform around accessibility and access-related safety

Recommendations 1.A through 1.D relate to improvement areas within existing regimes. The following set of recommendations for the federal government (1) and states (1) relates to creating new organizational responsibilities:

1. Create a federal entity that sets standards on passenger service transportation accessibility, including transportation network companies (TNCs) and on-demand autonomous mobility companies, and

2. Establish functions/ organizations at the state level that are able to regulate, monitor, and enforce the application of these standards. This function can be nested within existing regimes as long as its mandate aligns and it is empowered to do so.

For the federal entity, this may require the creation of an entirely new USDOT operating administration or perhaps a working committee within an existing administration that later expands the oversight reach of that administration. Determining which of the two options lies beyond the scope of this study. However, doing neither will likely serve to create a significant policy void in the near term.
The USDOT has eleven operating administrations, of which one looks mainly at manually driven vehicles (National Highway Traffic Safety Administration), another at the highways these vehicles run on (Federal Highway Administration), and one for public transit (Federal Transit Administration).

Between these, there is still a new frontier of transportation that has been rather ungoverned at the federal level for the past decade, which is purely passenger transportation mode with no operator onboard typically run by private companies. In years to come, the USDOT should at minimum set the national standard around driverless vehicle safety and access so that state, local and tribal governments can follow their lead.

At the moment, all of the AV operators' ODDs that the author is aware of are confined to one state per ODD. However, in the medium run with greater AV proliferation and acceptance, we can conceive of operators servicing cross-state much in the same way that trains went transcontinental in the 1800s and motor vehicles in the 1900s.

Standards should therefore be set at national scales for cross-country operations. While governance around safety is a bare minimum, when thinking about the future of transportation, our goals and aspirations should aim to encompass transportation access for a great number of Americans - to include traditionally underserved groups.

People only half-jokingly remark that vehicle automation is a tech innovation desperately looking for a problem to solve. In reality, the great divide and disparity in mobility access we have in the United States across dimensions of age, physical and cognitive ability, distance from urban cores, wealth, class, and race are among the most pressing problems vehicle automation has the latent ability to address.

As much as we have seen all of the AV companies assert that autonomy will lead to safer, more accessible and cleaner worlds, this promise is highly contingent on the path we chart with regards to which groups of people we choose to design, set policies/regulations, and create services for.
Starting with the paradigm of high contingency, this study has aimed to explore the importance of age-inclusive design at this juncture of active AV testing and deployment; to interrogate user needs in interacting with an autonomous vehicle for those who use mobility aids; and to provide a set of recommendations for

e) Vehicle designers and manufacturers (vehicle supply chain)
f) AV fleet planners and operators

g) Governmental and regulatory entities under their existing regimes - federal, state, local/ tribal, and

h) Advocacy groups.

5. Chapter Five - Areas for Further Research

Areas and topics for further research include:

1. A study exploring how AVs may be designed to align with the needs of cognitive and non-physical disabilities (including non-visible disabilities and episodic conditions)
2. A study focused on the cost vs. benefit of having accessibility/ caregiving assistants to accompany AV riders with special needs to ensure their safety, comfort, navigation at various user touchpoints, and to supplement some of the assistance that current human chauffeurs and drivers provide
3. A current state gap analysis on AV wheelchair accessibility with recommendations on how to improve the status quo
4. Built environment analysis on what needs to be changed or upgraded on urban roads, suburban or rural roads, signage, highways; who is responsible for upgrades and maintenance where AV services and use cross multiple jurisdictions and how projects of this nature can be financed
5. A survey of curb management regulations for AVs in major US metropolitan cities and areas for improvement
6. A cross-geographic comparison of AV development and accessibility practices across America, Europe, and Asia
7. How to enhance AV accessibility in the vehicle supply chain if and when full driving automation is offered in personally owned vehicles
8. A similar accessible design study related to public transit and publicly provisioned AVs

9. An evidence-based crash test and study on child safety across different autonomous vehicles
10. An evidence-based crash test and study on mobility device users across different autonomous vehicles

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7. Appendix

Appendix A - Participant Screening Questions

Screening questions were created and collected using Qualtrics (an online survey tool), and distributed using Constant Contact (an email distribution tool). The screening introduction and questions used are included below:

Title: Study - Vehicle Interior and Spatial Considerations for Driverless Mobility

MIT AGELAB

Life Tomorrow

MIT's Age Lab is seeking participants for virtual interviews about travel behavior and emerging mobility solutions (esp. autonomous vehicles). Interviews will engage participants on their own travel (and potential accessibility) needs - focusing on the interior space of vehicles.

We would value your thoughts and travel experiences on the topic. Respondents who meet the study criteria and participate will receive a $40 gift card for their time, and interviews will be conducted via Zoom and last approximately 60 minutes.

If you are interested in taking part in the study, please fill out this brief questionnaire by this Monday (01/23/23) to determine your eligibility. If you qualify to participate, we will reach out to you by email to schedule a Zoom Call.

This questionnaire will take approx. 5 minutes to complete and participation is completely voluntary. If you feel uncomfortable answering any questions, you may quit the survey at any time or skip the question where it is permitted.

If you have any questions or concerns about this study you can contact David Hong via phone (617-335-2200) or e-mail (hongdav@mit.edu).

{end of message}

Q1 Would you like to participate in this interview?

- o Yes (1)
- o No (2)

Skip To: End of Survey If Q1 = No

Q2 Do you have a computer or mobile phone with a working web camera, working audio features, and stable and reliable internet access in your home?

- o Yes (1)
- o No (2)
- o Don't Know (3)

Skip To: End of Survey If Q2 != Yes {Note: The "!=" symbol means 'not equal to'}

Q3 Have you comfortably used Zoom to participate in a video call before, and would you be able to participate in an interview via Zoom?

- o Yes (1)
- o No (2)

Skip To: End of Survey If Q3 != Yes

Q4 Please select all that apply (can select multiple). In the past 12 months, have you or anyone in your household used any of the following aids or devices when moving about?

This person could be yourself, or an adult of any age who is living in your immediate household.

- ▢ Walker (1)
- ▢ Rollator (2)

- ▢ Cane (3)
- ▢ Crutches (4)
- ▢ Service Animal (5)
- ▢ Motorized/ power scooter (6)
- ▢ Wheelchair/ power wheelchair (7)
- ▢ None of the Above (8)
- ▢ Something else (please specify name and briefly describe the mobility aid/ device): (9) ____

Display Q5 Question:
If Q4 != None of the Above

Q5 What is your relationship with the person in Question 4?

(e.g. self, parent, daughter, sibling, relative, etc)

____

Q6 Are you a parent?
- o Yes (1)
- o No (2)

Q7 Have you used a baby stroller for your child in the past 12 years?
- o Yes (1)
- o No (2)

Q8 How often do you travel on an airplane with luggage (checked or carry-on)?
- o Weekly or more often (1)
- o Once or several times a month (2)
- o Occasionally (e.g. on vacation, to visit others, etc) (3)
- o Never or almost never (4)

Q9 How comfortable are you being driven by another experienced driver?

	I don't trust anyone else's driving ability and would not take a ride (1)	moderately uncomfortable (2)	neutral (3)	moderately comfortable (4)	I am completely comfortable (5)

Comfort Level	o	o	o	o	o

Q10 How open are you to the thought of riding in a fully autonomous vehicle?

(where the vehicle and the supporting technology are designed to handle every part of the trip, from start to stop, without the help of a human driver)

- o Never - I would never take a ride in a driverless vehicle, no matter how safe it becomes or is purported to be in the future (1)
- o Unlikely - I am very unlikely to ride in a driverless vehicle, no matter how safe it becomes or is purported to be in the future (2)
- o Potentially - I am potentially open to try a driverless vehicle, if the conditions are made suitable (e.g. affordable, convenient, safe, etc) (3)
- o Likely - I would love to try a driverless vehicle, if the conditions are made suitable (e.g. affordable, convenient, safe, etc)> (5)
- o Certainly - I would love to try a driverless vehicle, no matter how safe it becomes or is purported to be in the future (6)

Q11 First and Last Name

____

Q12 Email Address

____

Q13 In what year were you born?

____

Skip To: End of Survey If Condition: In what year were you born? Is Greater Than 2003. Skip To: End of Survey.

{Note: This question was included to ensure that no minors were interviewed to be compliant with COUHES requirements}.

Q14 Gender

- o Male (1)
- o Female (2)
- o Non-binary / gender non-conforming (3)
- o Prefer not to say (4)

Q15 How many days per week do you typically drive?

- o 0 days (1)
- o 1-2 days (2)
- o 3-4 days (3)

- o 5 or more days (4)
- o Don't know (5)

Q16 Which of the following best describes the area where you live now? (residence where you spend the most time)

- o Urban (1)
- o Suburban (2)
- o Rural (3)

{end of survey}

Appendix B – Interview Guide

Interviews followed a semi-structured format, generally adhering to the flow of the interview guide, but adjusting contextually.

Introducing the Study

Hello, so nice to meet you! Before we begin, may I video/ audio record this session? {Receive consent} [turn on video recording]

My name is David Hong, I research transportation, aging and age-related vehicle accessibility at MIT. I'm conducting a study that thinks about the interior of future on-demand vehicles (those that would be summoned) and what features, and elements are important for their travel experience.

Do you have any questions
To thank you for your participation, we will email you a $40 amazon gift card within 5-10 business days upon completing the interview. The consent form I shared ahead says that you can withdraw from the interview at any time, information gathered will be used, but your name etc will be omitted for privacy. At this point, I'm just going to re-ask if you consent to a) this interview and b) having it video/ audio recorded.

Preliminary Interview Questions

1. With housing keeping out of the way, could you please tell me **where** you live, **how** you typically get around?

2. **Range** - What is your typical travel radius (in miles)?

3. **Family -** Who do you live with?

4. **User Journey -** Could you describe a typical journey for me from the moment you decide to make a trip, how you get ready to the moment you either arrive at a set destination?

5. Pain points - what are your greatest pain points? What more do you aspire to do - mobility-wise?

Some examples of trip types can be:

Work	
School/ Institutional/ Religious	
Medical/ Dental	
Shopping/ Errands	
Social/ Recreational	
Transport Someone	
Meals	

Additional Probes (Optional)

- What is the decision making process in choosing how to get somewhere and how early do you need to plan this trip? (what factors weigh in)
- What do you usually take with you? How important is it to have that when traveling? How likely would you be to make the trip if you couldn't take it with you?
- Where do you store the device/ luggage?
- How much space do you need for that?
- Were you ever unable to travel because of this space requirement?

6. **Mobility Device -** You've (not) indicated that you or a household member has traveled with a mobility aid/ device in the past 12 months. Remind me what it was, and if comfortable, would you mind talking about that a little bit?

How does it currently shape the ways in which you're able to travel, and ways you're unable to travel?

7. **Non-Spatial Factors -** other than space allowance, what other factors shape your access to mobility and transportation?

What other needs or accommodations are useful in enabling your travel / provide you comfort?

8. **Driverless vs. Driver -** Are there ways in which drivers offer you assistance prior to, during, or at the conclusion of your trip?

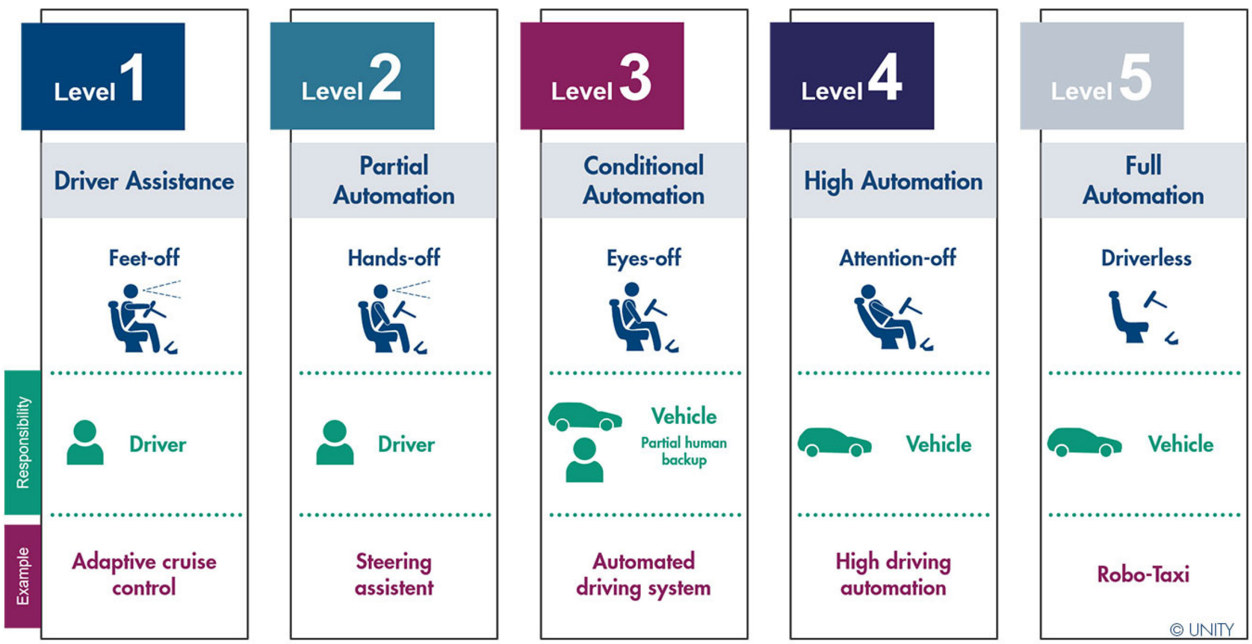
[ONLY if asked - e.g., carrying, lifting, adjusting, storing, unloading items, or sharing information]

How do you imagine the same task may be carried out in the absence of a human driver?

9. **Gaps -** Thinking about the way you travel now, do you have any frustrations or design modification suggestions you have for cars or future vehicles?

10. **Features -** What are some features of the car that you like and help you?

Visual Reference to Explain Levels of Automation and that we are specifically going to discuss Levels 4 and 5 where the vehicle can be modified to remove human driver components.



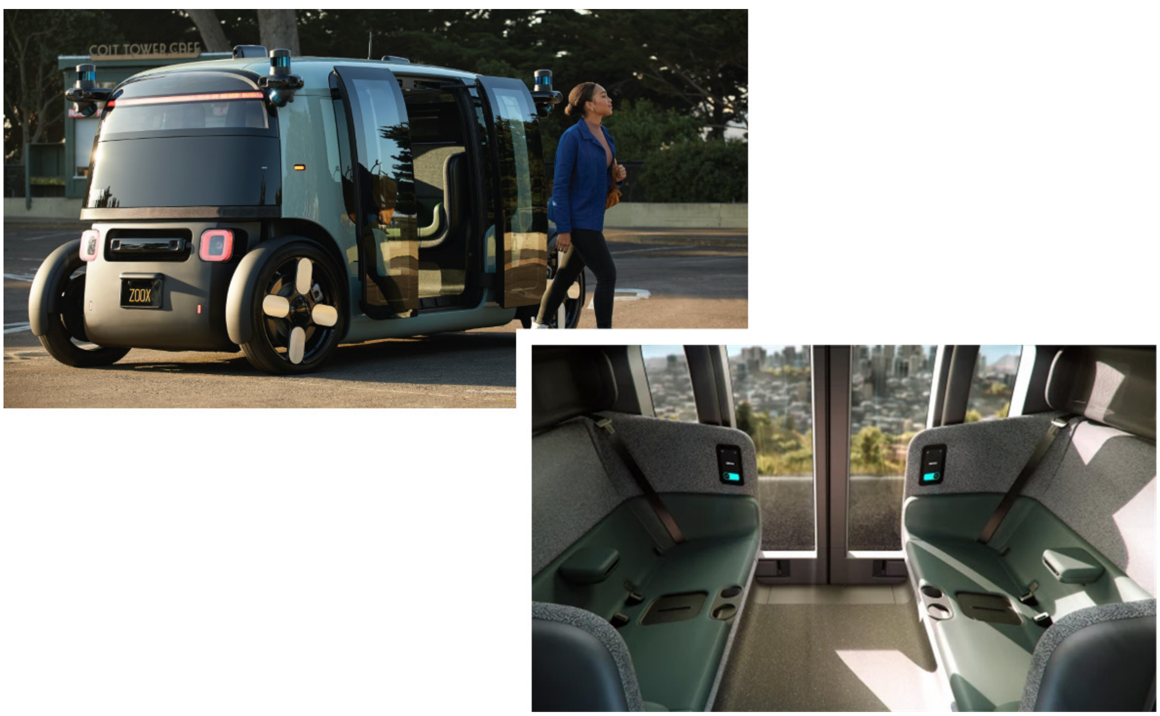
11. If you were to redesign or modify, what features would you introduce and **why**? What do you think would be the top 2-3 things you would change or improve? Why?

12. What do you perceive the main societal, personal benefits autonomous vehicles will bring?

13. What do you see as the potential downsides?

Visual References for Discussion used approximately at the 30-40 min mark.

Credit: Cruise



Credit: Zoox

Credit: Canoo

Credit: Benteler Group, Holon

Credit: Cruise

Credit: Waymo

Credit: Waymo

Thank you so much for our conversation, and if you have any questions or more opinions/ revisions on opinions you'd like to share in coming days, please let me know.

I will be in touch re compensation, and if there's an opportunity for re-engagement (i.e., a 2nd chat on this same topic), would it be alright if I reach out?

{End of section}

COUHES Exemptions

Appended on following pages

Massachusetts Institute of Technology
Committee on the Use of Humans as Experimental Subjects
77 Massachusetts Avenue Building E25-143B Cambridge, MA 02139-4307

Submission Date: Apr-07-2022

Title: E-3977, Study into Post-Retirement Accessible Mobility Options
Principal Investigator: Hong, David Suk
Department: Urban Studies and Planning
Faculty Sponsor: Coughlin, Joseph F
Start Date: Apr-08-2022
End Date: May-31-2023

Determination: Exempt

Your research activities meet the criteria for exemption as defined by Federal regulation 45 CFR 46 under the following:

Exempt Category 3 - Benign Behavioral Intervention

Research involving benign behavioral interventions where the study activities are limited to adults only and disclosure of the subjects' responses outside the research could not reasonably place the subjects at risk for criminal or civil liability or be damaging to the subjects' financial standing, employability, educational advancement, or reputation. Research does not involve deception or participants prospectively agree to the deception. 45 CFR 46.104(d)(3)

Exempt Category 2 - Educational Testing, Surveys, Interviews or Observation

Research involving surveys, interviews, educational tests or observation of public behavior with adults or children and disclosure of the subjects' responses outside the research could not reasonably place the subjects at risk for criminal or civil liability or be damaging to the subjects' financial standing, employability, educational advancement, or reputation. Research activities with children must be limited to educational tests or observation of public behavior and cannot include direct intervention by the investigator. 45 CFR 46.104(d)(2)

All members of the research team must adhere to the policies as outlined in the [Investigator Responsibilities for Exempt Research]. If the facts surrounding your evaluation change, you are required to submit a new Exempt Evaluation. Research records may be audited at any time during the conduct of the study.

email: couhes@mit.edu | phone: 617-253-6787 | website: couhes.mit.edu

Massachusetts Institute of Technology
Committee on the Use of Humans as Experimental Subjects
77 Massachusetts Avenue Building E25-143B Cambridge, MA 02139-4307

Submission Date: Feb-23-2023

Title: E-4703, Vehicle Interior and Spatial Considerations for Driverless Mobility
Principal Investigator: Hong, David Suk
Department: Urban Studies and Planning
Faculty Sponsor: Coughlin, Joseph F
Start Date: Feb-14-2023
End Date: Jun-01-2023

Determination: Exempt

Your research activities meet the criteria for exemption as defined by Federal regulation 45 CFR 46 under the following:

Exempt Category 3 - Benign Behavioral Intervention

Research involving benign behavioral interventions where the study activities are limited to adults only and disclosure of the subjects' responses outside the research could not reasonably place the subjects at risk for criminal or civil liability or be damaging to the subjects' financial standing, employability, educational advancement, or reputation. Research does not involve deception or participants prospectively agree to the deception. 45 CFR 46.104(d)(3)

Exempt Category 2 - Educational Testing, Surveys, Interviews or Observation

Research involving surveys, interviews, educational tests or observation of public behavior with adults or children and disclosure of the subjects' responses outside the research could not reasonably place the subjects at risk for criminal or civil liability or be damaging to the subjects' financial standing, employability, educational advancement, or reputation. Research activities with children must be limited to educational tests or observation of public behavior and cannot include direct intervention by the investigator. 45 CFR 46.104(d)(2)

All members of the research team must adhere to the policies as outlined in the Investigator Responsibilities for Exempt Research. If the facts surrounding your evaluation change, you are required to submit a new Exempt Evaluation. Research records may be audited at any time during the conduct of the study.

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