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ACCESSIBLE, BARRIER-FREE MOBILITY

Literature Review conducted by ITS America, with the support of AARP and the Autonomous Vehicle Alliance

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TABLE OF CONTENTS

INTRODUCTION

Mobility is an important part of everyday life – fundamentally impacting one's ability to obtain and maintain employment, attend school, access goods and services, and engage with the world. Even as communication technology and connectivity improves (better enabling individuals to work, socialize, and access goods without leaving their house), accessible roads, routes, and transportation options remain critical to ensuring safe, equitable, and inclusive communities.

Often, issues of accessibility are discussed with the disability community in mind, including (but not limited to) individuals who face limitations associated with physical mobility, vison, hearing, or cognition. Overcoming barriers faced by members of this community is critical to a transportation network that is accessible to all. There are, however, a range of other factors that can also inhibit independent mobility.

Barriers to mobility may, for example, be associated with:

- **Physical limitation or disability** (for instance, loss of hearing, vision, mobility, dexterity, etc.)
- **Cost** (financial barriers, such as prohibitively expensive fares or membership fees)
- **Coverage**: issues of distance or time (gaps in transportation service or availability; for instance, there may be a lack of nearby or timely accessible mobility options needed to cover the complete trip)
- **Safety/Security** (physical well-being, data privacy, etc.; concern regarding the security of passengers, mobility devices, and personal information across the complete trip)
- **Awareness** (limitations associated with knowledge or understanding of available transportation options, related devices/services, eligibility for reduced fare programs, etc.)
- **Technical limitations** (inability to access or use technology – due to, for instance, lack of a smart phone, credit card, etc.)
- **Design/Upkeep** (a system or service's capacity to function smoothly/effectively for all users; limitations associated with road layout, pavement quality/maintenance, congestion, or design bias – for instance, certain groups may be underrepresented in mobility-related datasets/AI, etc.)

For mobility to be "barrier-free" a transportation ecosystem – including the streets, sidewalks, transit, associated technologies, etc. – must be accessible to all users. To this end, it is important for transportation-related devices, services, and spaces to be affordable, understandable, safe, reliable, and usable. A system that is accessible to those who may otherwise face mobility-related hurdles (be the person a wheelchair user, low-vision, low-income, a minor, etc.), will be better for everyone.

This literature review will provide insights into the current transportation ecosystem and how emerging mobility trends and technologies can be (and/or are being) leveraged to support and improve accessible and barrier-free mobility for all. This review will focus on the following key topics:

- **Complete Trip**: outlining the importance of the complete travel chain, from origin to destination (including pre-trip planning, wayfinding, travel mode transfers, and navigation to/within public spaces and buildings), and the need for every step of the Complete Trip be accessible.
- **Automation**, exploring the potential role of new and developing automated technology, with a focus on automated vehicles (AVs) – from full-size automobiles to personal automated wheelchairs.
- **Mobility on Demand** (MOD), discussing the range of emerging shared mobility services, pilots, partnerships, and trends, and the impact that these developments may have on accessible mobility.
- **Accessible streets**, focusing on curb management and Complete Streets design concepts that may encourage alternative forms of transportation.
- **In-hand technology**, examining how accessible interfaces, handheld technology, and smartphone apps, are aiding mobility and helping to reduce travel-related barriers.
- **Conclusion**, providing key findings and takeaways regarding the potential impact of emerging transportation trends and technology on accessibility, and associated needs & considerations for working towards a more universally accessible transportation ecosystem in the future.

This literature review was conducted by the Intelligent Transportation Society of America (ITS America), with the support of the AARP and the Autonomous Vehicle Alliance (AVA).

MOTIVATION

Access to barrier-free mobility is in everyone's best interest. An individual's ability to move independently is critical to foundational elements of a productive, healthy lifestyle – from enabling people to seek and sustain employment, to making it possible for people to meet and engage with other members of their community. Even if a given individual is not themselves directly impacted by a specific mobility challenge, a system that is more accessible to that person's family members, friends, and co-workers will offer greater utility. If the entire system is more accessible to those who face specific barriers, it will likely be more accessible to general users as well. For example, wheelchair ramps, or "curb cuts" for crosswalks at intersections are not only beneficial to the mobility of individuals in wheelchairs, but also make it easier for other road users to travel with wheeled items – from bicycles to rolling luggage to strollers. Similarly, pedestrian islands across busy intersections give an older adult with limited mobility, a person in a wheelchair, or a child walking with a parent time to get across a busy intersection.

While much has been done to make the transportation ecosystem more accessible (for example, wheelchair-accessible buses, and auditory cues at crosswalks), various communities and individuals continue to face a range of challenges and barriers to completing trips in a manner that is timely, affordable, safe, and/or effective for their needs. The number of people impacted by barriers to accessibility is significant. For instance:

THE DISABILITY COMMUNITY

According to the United States Centers for Disease Control and Prevention (CDC), 61 million adults in the United States, more than 1 in 4 U.S. adults (and about 2 in 5 adults age 65 years and older), live with a disability.[1] Further, the probability of an individual experiencing a temporary mobility impairment is 95%, meaning that most people are likely to experience a mobility impairment at some point during their life.[2]

Barriers associated with transportation and accessibility continue to inhibit members of the disability community. For instance, individuals with disabilities are more likely to face greater financial burden associated with mobility. As an example, the cost to make a vehicle handicap accessible often is at least $15,000;[3] this added expense is equivalent to a 50% increase on the price of the average new vehicle.[4] Those facing these extra costs may also be less likely to afford it; while the median income of those without a disability in the U.S. is approximately $30,500, the median income for individuals with a disability is approximately $20,250.[5] Burdens associated with the added cost of personal mobility can make it more difficult to travel to work or live independently.

Furthermore, in addition to cost, lack of transportation availability can be a problem for members of the disability community. According to the Bureau of Transportation Statistics, 12% of individuals with disabilities have difficulty getting needed transportation, whereas 3% of individuals without disabilities face this problem. This means that individuals with disabilities are four times more likely to not have access to the transportation they need. (Note: For these individuals without disabilities, 47% stated that their difficulty in acquiring transportation is due to a lack of or limited local public transportation.[6] Later in this literature, the emergence of services aiming to address gaps in transit will also be discussed, as transportation coverage is also critical to accessible mobility.) Some individuals with disabilities may be unable to drive, and therefore are more dependent on existing transportation services. While the ADA requires equivalent services to those unable to utilize traditional fixed route service, paratransit service often requires 1-2 days advance notice, riders complain of service not arriving as scheduled, and paratransit costs per rider are much higher than traditional fixed-route service.

AGING & INDEPENDENT TRAVEL

As people age, transportation options often become more limited. For instance, 81% of adults in the US over 65 years of age still have their driver's license, meaning that almost 1 in 5 are no longer able to drive safely.[7] Studies show that the loss of driving can result in increased isolation due to loss of mobility and is associated with an increased risk of depression. With a growing aging population outliving their safe driving years by about a decade, maintaining safe, accessible options for independent mobility is critical and enables them to remain connected, healthy, and engaged in their community.[8] A system that may also help to alleviate transportation barriers for older adults as their transportation needs shift over time should also be helpful and accessible to the disability community, with sufficient options for those who are unable to operate a vehicle independently.

FINANCIAL AND TECHNICAL LIMITATIONS

More than 25% of U.S. households are unbanked or underbanked, according to the Federal Reserve's 2017 Household Survey.[9] As new, on-demand mobility services and applications emerge, for instance, it is important that platforms be designed to accommodate various methods of payment, not just a credit card, so that the unbanked and underbanked do not get left out.

Emerging services and technologies, such as Mobility on Demand, often provide limited or no service within lower-income areas. For example, Via first launched its microtransit service in Washington, DC in August 2016.[10] While most of the city was within their service area, Wards 7 & 8 – east of the Anacostia River, and historically low-income neighborhoods – were not in the service area. The Mayor issued a 90-day warning to Via stating that they are required to provide service across all areas of the city in April 2018,[11] and Via expanded its service area to cover the entire city within the month.[12]

Smartphone ownership, or lack thereof, presents a similar concern. Not everyone has a smartphone. While smartphone penetration has reached approximately 67.3% of Americans (as of 2017),[13] that still leaves over 100 million people in the U.S. without a smartphone. Limited access to smartphones could be due to many differing factors, such as device or service cost, provider service area, or even the adoption of new technology. While smartphones are becoming valuable tools for improving mobility and accessibility (as they can be leveraged increasingly for everything from wayfinding to trip planning), it is also important to recognize that requiring the use of such devices could leave out some users. For this reason, transportation options that offer trip planning or reservation service through a mobile app should also provide computer-based or call alternatives for these functions.

The motivation for exploring issues pertaining to transportation accessibility is that a wide and diverse range of people can be left out if a system is not designed in an informed and intentional way. Better understanding of current barriers to mobility, as well as how the transportation ecosystem is evolving with the addition of new services and technologies, can help to potentially alleviate these barriers moving forward.

Mitigating barriers to mobility can increase employment access and economic engagement. Expanding services, such as Mobility on Demand, can bridge gaps in transit coverage. With the continued expansion of smartphone deployment, in-hand assistive aids can help all individuals navigate complex and unfamiliar environments. Complete Streets design philosophies can encourage alternatives to the private automobile and provide ample space for bicycles and scooters without interfering with pedestrian spaces. Looking further into the future, AVs could help individuals with accessibility needs have equal access to transport as individuals without disabilities.

Mobility is critical to productivity and quality of life, enabling individuals to engage with and contribute to society. The population of Americans with accessibility barriers is sizable – and with the baby boomer generation aging, it will likely continue to grow. This literature review will identify some key trends, programs, and technologies emerging in the transportation sector and highlight the potential role they could play in helping to increase accessible and barrier-free mobility for all.

COMPLETE TRIP

The "Complete Trip" refers to the seamless journey from a traveler's origin to destination, regardless of the number of modes, transfers, or connections.[14] The idea is that if a single hurdle or challenge severs the travel chain, then it does not constitute an accessible trip. While the accessibility of the vehicle itself is important, and the focus of accessibility budgets for local transit agencies is often on ensuring vehicle fleets are accessible, the focus of the Complete Trip concept is to ensure accessible and barrier-free mobility in every step of the journey for the user with accessibility needs.

There are five steps to the Complete Trip travel chain:

1. Plan and Book a Trip
2. Travel to Transit Station
3. Ride the Bus
4. Cross the Street
5. Arrival at Destination

Figure 1: Complete Trip diagram. Source: USDOT

In order to remedy common hurdles to satisfying the Complete Trip, the United States Department of Transportation (USDOT) launched the Accessible Transportation Technologies Research Initiative (ATTRI). This joint initiative is co-led by the Federal Highway Administration (FHWA), Federal Transit Administration (FTA), and Intelligent Transportation Systems Joint Programs Office (ITS JPO), with support from the National Institute on Disability, Independent Living, and Rehabilitation Research (NIDILRR) and other federal partners. ATTRI's goal is to work with transit agencies and the stakeholder community to address all parts of the travel chain, allowing individuals with disabilities to have independent access to work, education, health care, and social and recreational activities.

ATTRI's project funding focused on bridging the gaps that occur in fulfilling the Complete Trip for individuals with accessibility needs. These applications were focused into four areas that are common gaps in the Complete Trip travel chain:

Pre-trip concierge & virtualization – an application suite that supports pre-trip planning for individuals with cognitive disabilities. The applications are to assist users in trip planning, booking, and en route travel information, as well as creating a virtual environment for users to familiarize themselves with travel before the trip.[15]

Automation & robotics – assistive technologies that include collaborative robots that assist individual users with everyday tasks; robots that provide related services at different points of travel; and even automated vehicles.[16]

Wayfinding & Navigation – helps travelers with disabilities safely and independently reach their destinations by providing real-time information, localization, and situational awareness to assist in navigating environments, including path planning and detouring around blocked routes and hazards. Applications that guide wheelchair users and people with visual impairments along routes using smart phones and other assistive technologies.[17]

Safe Intersection Crossing – uses connected vehicle technology to connect pedestrians with the traffic signal system to increase the safety of intersection crossings and improve independent mobility. This technology enables pedestrians to use their connected mobile devices to interface with vehicles, traffic signals, and other infrastructure to receive context-based information related their surroundings, helping the pedestrian to cross the intersection safely.[18]

An example of the steps of the Complete Trip is shown in Figure 1. Projects and technology being implemented to assist in the Complete Trip travel chain are discussed below. It should be noted that some of the projects funded through ATTRI are covered in other sections of this report.

ABLELINK SMART TRAVEL CONCIERGE SYSTEM

AbleLink is a company that develops technologies designed to enable individuals with cognitive disabilities to perform everyday tasks and live more independent lives. As part of ATTRI's Complete Trip philosophy, AbleLink developed the Smart Travel Concierge System (STCS). This pre-trip concierge and virtualization project is designed to facilitate pre-trip planning and virtualization for individuals with cognitive disabilities. The STCS will help individuals acquire the necessary skills for traveling independently as well as perform the pre-trip preparation activities necessary for successful use of public transportation.[19,20]

Cognitive design strategies are used to develop or repurpose each of the technologies that are incorporated into the STCS. These technologies also guide the design of the new virtualization and transportation specific content that are developed in this project. The STCS includes trip virtualization capabilities that help enable individuals to simulate a specific travel trip, including first/last mile; sites passed during the trip, to aid wayfinding so the individual will know when to notify the driver to stop the bus or which train stop to get off at; and other pertinent information about the trip that may be relevant.

STCS is a suite of technologies that work together to support necessary assessment, self-directed training, pre-trip planning, and virtualization activities developed specifically for individuals with cognitive disabilities. These technologies have a goal of supporting independent use of traditional, fixed route public transit, reducing the need to use costlier paratransit services. The suite of tools includes:

- Transportation Readiness Assessments, a series of cognitively accessible tools that facilitate the self-assessment of important skill areas to evaluate transportation readiness and identify areas where training is needed.
- Transit Skills Training System, the development of a universally designed learning curriculum targeted on skill areas relevant to using public transit.
- Schedule Support App, cognitively accessible time-based prompting technologies for pre-trip preparation and travel schedule maintenance.
- Pre-Trip Virtualization, allowing individuals to prepare for each step of their trip by viewing computer-animated scenarios of the upcoming transportation event prior to departing on a trip.

Together, these tools will advance ATTRI objectives by providing individuals with cognitive disabilities hands-on tools to support transportation readiness, and individualized training to prepare themselves for independent use of fixed route transit systems. This, in turn, could reduce reliance on specialized transportation services, which are often heavily subsidized.

Utilizing STCS, AbleLink expects to see a 50% increase in use of fixed-route transit services, and a 25% decrease in paratransit use for individuals with cognitive disabilities. AbleLink also expects travelers with cognitive disabilities to experience an increase in ease of use of the transportation system. The increased use of traditional fixed-route services and the reduced use of paratransit services will lead to reduced total costs for transit agencies.

ABLELINK – SMART WAYFINDING STANDARD

AbleLink is developing the Specialized Media for Assisting Route Travel (SMART) Wayfinding Standard, a common route format for presenting travel instructions to individuals with cognitive disabilities, encouraging their independent use of public transit. AbleLink is developing the standard in cooperation with the ARC of Albuquerque, Ability Beyond, and the Project Steering Committee. This project identifies and develops the standard to facilitate independent use of public transportation by individuals with cognitive disabilities. By developing a "de facto" industry standard, the ATTRI program will encourage new wayfinding technologies to be developed for individuals with cognitive disabilities and others with special needs. Further, cloud-based tools will further promote the use of this new standard by simplifying the creation of new routes and allowing users greater access to SMART-compliant routes in their region.[21,22]

When complete, these tools will include:

- Travel Manager – a web-based tool for simplifying the ability to create SMART compliant travel routes for various destinations
- SMART Travel Library – a cloud-based library of routes to specific destinations that will provide easy access to SMART compliant routes for specific geographic areas which can be downloaded and used as-is, or modified to meet the needs of travelers with cognitive disabilities and others with special needs
- Wayfinder mobile app – a mobile app that will utilize SMART-compliant routes for desired destinations to provide geolocation-based multimedia instructions to individuals with cognitive disabilities to facilitate independent travel

Together, these tools will advance ATTRI objectives by providing innovative wayfinding technologies for helping individuals with cognitive disabilities to independently use the fixed route transit system and move away from more costly specialized travel services, such as paratransit. AbleLink estimates a 50% increase in the use of fixed-route transit services, and a 25% decrease in traditional paratransit use by individuals with cognitive disabilities. This would lead to decreased transit costs, due to reducing the demand for highly subsidized paratransit.

TRX SYSTEMS – SMART WAYFINDING AND NAVIGATION (SWaN)

TRX Systems is a developer focused on mapping and locating indoor environments, particularly areas that cannot utilize GPS sensors. One of their developments is NEON, creating structure maps using a variety of sensors. Building upon their NEON developments, TRX Systems is developing the Smart Wayfinding and Navigation (SWaN) mobile application, a navigation and wayfinding mobile service with open APIs delivering localization, orientation, waypoint navigation, route guidance, and advanced warning of events within complex structures. This will provide the necessary tools for path planning and routing, real-time location, en route assistance, and situational awareness. The SWaN service will run on standard smartphones, with or without a NEON tracking unit wearable accessory, allowing users to choose the platform and accuracy tailored to their needs.[23,24]

The SWaN system will support navigation and routing in complex, overlapping above and underground structures. It is a cloud-based system, utilizing crowdsourcing of navigation maps and community-contributed route data. As part of the ATTRI project, TRX Systems will develop open APIs for program and commercial partners, to allow the project to scale. With the SWaN system development, TRX Systems expects to expedite accessible location/wayfinding/navigation app development. The initial focus of development will be on complex public buildings and transit structures, which can be difficult to navigate. TRX also intends to support other application developers focused on expanding independent travel for people with disabilities.

TRX Systems is the lead organization for the SWaN project, with support from the University of Maryland and the National Federation of the Blind. TRX Systems will continue to develop the SWaN project and will be reaching out to application developers over the coming months, including a developer program to deliver information, tools, and the support required by accessible application developers. They will also participate in accessibility-focused hackathons to encourage application development and reach out to standardization efforts like Wayfinder to ensure best practices are shared among the community.

OTHER ATTRI PROJECTS

Carnegie Mellon University is developing a Safe Intersection Crossing app, utilizing a smartphone with an add-on DSRC antenna to facilitate communications between the pedestrian and surrounding infrastructure. This project will be covered more in the Accessible Streets section of this literature review.

PathVu Navigation (formerly AccessPath) is a wayfinding app for individuals with accessibility needs or visual impairments, directing pedestrians along unobstructed routes. This project will be covered in the Accessible Streets section of this literature review.

The City College of New York is developing the Smart Cane for Assistive Navigation (SCAN), a hardware interface that would aid users with independent travel in high-volume public spaces, including transportation terminals and outdoor pedestrian environments. This project will be covered in the In-Hand Technology section of this literature review.

SMART PARKING

The conclusion of a private vehicle Complete Trip often requires parking the vehicle. However, if the destination is in the city center or another popular location, locating a parking spot can be difficult. Some statistics suggest that drivers searching for parking make up approximately 30% of city traffic, congesting parking lots, spilling into roadways, and increasing pollution.[25] The growth in deployment of smart parking systems can help users locate available parking inventory, saving time and money.

Figure 2: Image depicting Smart Parking via mobile application; Source: [Happiest Minds]

Smart parking systems collect and disseminate parking inventory data that can be used to inform and expedite parking. Smart parking systems can help on a small and large scale; these systems can direct drivers to available spaces and facilitate payment and can help municipalities understand parking demand. With the continued growth in Internet of Things (IoT) and the number of connected devices rises, there are opportunities for further information dissemination and travel efficiency improvements.

Many public parking garages, such as those at airports and shopping malls, feature parking guidance information (PGI) boards. These boards inform drivers of parking space availability in an indicated direction, row, or level of a parking facility. Some garages also include overhead indicators above every parking space that make it easier for drivers to identify an empty space from a distance. Smart parking systems could also incorporate other technologies and capabilities, managed by a central data management system. This data can be incorporated into a broader smart city infrastructure, allowing further dissemination to the public.[26]

As an example, the San Francisco Municipal Transportation Agency's (SFMTA) smart parking initiative allows customers to view current availability of some on-street parking areas, and view their current demand-based prices via mobile app. The pilot project successfully maintained the targeted level of parking occupancy, while reducing parking-related vehicle cruising by 50%.[27]

Some companies are incorporating smart parking technologies to specifically assist individuals with disabilities. Blue Badge Parking is a crowd-sourced mapping tool that directs users the disabled parking space closest to the user's location.[28] Apps like Blue Badge Parking, or specialized filters within more generalized apps like Google Maps or Apple Maps, could be used in combination with smart parking systems to guide individuals with specific mobility needs to appropriate parking spaces.

Smart parking systems provide real-time information to customers to better inform their parking decisions and save time. Further, this information can be useful to departments of transportation and urban planners for determining future infrastructure improvements and traffic mitigation strategies. Smart parking has the potential to reduce congestion in cities as well as aid in future city planning and investment decisions, while also providing a useful service to residents and visitors.

Figure 3: A screenshot from San Francisco's smart parking initiative. The street parking and city-owned garages with demand-based pricing are shown in green gradient, with darker green being more expensive per hour; Source: SFMTA

CONSIDERATIONS

Barrier-specific Commentary: Complete Trip

Mobility Barrier	Select Comments
Physical limitation or disability	• Developing services with the "Complete Trip" philosophy in mind can help support fully accessible trips, from origin to destination. • ATTRI has supported a variety of projects aiming to remove barriers for a variety of physical and cognitive disabilities. • Programs and initiatives such as STCS and the SMART wayfinding standard may provide individuals with cognitive disabilities tools to support safe, independent mobility.
Coverage	• Technologies such as SCaN and SWAN can assist with wayfinding and navigation in various environments, helping to connect travelers to their destination.
Design/Upkeep	• Smart Parking can help alleviate congestion and allow commuters to more efficiently end their trip.

AUTOMATION

Developments in the field of automation present the potential to transform the transportation sector. From driverless vehicles to automated wheelchairs, these emerging systems could help to alleviate some barriers to mobility and increase accessibility.

AUTOMATED VEHICLES

AVs are automobiles with the sensors and software necessary to provide some form of automated driving. The Society of Automotive Engineers (SAE) has developed the J3016 standard, subdividing the amount of autonomy of a vehicle into six levels, Level Zero (no automation) to Level 5 (full autonomy). Current vehicles with features such as lane centering or adaptive cruise control are considered Level 1; Autopilot, which features simultaneous lane centering and adaptive cruise control, makes the Tesla a Level 2 AV. Several companies are currently developing vehicles with more advanced levels of automation, but there are currently no Level 4 or 5 AVs available to the public.[29]

AVs have the potential to improve the lives of people with disabilities, the elderly, and travelers of all ages, by offering a (potentially safe and efficient) way to get around that would not require the ability to drive. On-demand, automated transportation could increase an individual's ability to travel independently and trip plan flexibly. Particularly if vehicles are designed accessibly, this technology could significantly improve mobility for a wide range of individuals who have traditionally faced transportation barriers.[30]

There are several companies developing AVs, with some even testing on public roads. Due to both the technological regulatory hurdles of testing the technology, many of these AV developers are conducting testing with low-speed vehicles on public roads. Some examples of companies developing AVs include:

- May Mobility: May Mobility, a transportation startup, is developing a low-speed, electric, wheelchair-accessible AV. Their prototype vehicle includes wide access doors and built-in ramps to accommodate accessible on-boarding and off-boarding, as well as parts needed to secure a wheelchair once it is inside the vehicle. May Mobility has sought vehicle design feedback from the disability community in Columbus, Ohio, who have suggested improvements such as more gradual ramps and optimized pick-up and drop-off points.[31]
- Voyage: Voyage is another company testing low-speed AVs, deploying their fleet in two retirement communities: one near San Jose, California, and the other in The Villages, Florida. Voyage offers AV shuttle services to various parts within these communities; this provides not only a much-desired transportation service within the older community, but also a real-world test bed for the developers and an avenue for older individuals to experience and adjust to AVs over time.[32]

Automation can also be leveraged to aid mobility off road (indoors, in parks, etc.) as well. For instance, Whill, a manufacturer of personal mobility devices, is developing a personal, autonomous, electric wheelchair. The vehicle includes sensors and automatic brakes to detect and avoid obstacles throughout the service area. Currently targeted for large public spaces, such as airports and conference centers, the personal AVs could pick up passengers from the curb and take them to their destination (a boarding gate, etc.). Once the trip is complete, the vehicle would autonomously return to its charging station until dispatched again. The Whill personal electric AV has been undergoing both semi-autonomous and full autonomous trials in several large airports, like Tokyo Haneda Airport and Dallas-Fort Worth International Airport.[33]

Figure 4: Whill personal electric autonomous vehicle; Source: Inventiva

AUTOMATED DEVICES FOR MOBILITY & SIMILAR TECHNOLOGIES

Jaguar is developing a "mobility door" for their vehicles. The door is designed to open automatically when approached by a person with a key fob. The door is equipped with radar sensors and gesture control, preventing the door from opening into other objects and closing without needing additional input from the individual. This technology could help customers with disabilities get into and out of the vehicle more easily.[34]

Other technologies and systems, such as SWaN, pathVu Navigation, and Smart Cane, will be covered elsewhere in this literature review. SWaN is covered in the Complete Trip section; pathVu Navigation is covered in the Accessible Streets section; and the City College of New York's Smart Cane project is covered in the In-Hand Technology section of this literature review.

CONNECTED-AUTOMATED TECHNOLOGY

The broad deployment of connected-automated technology could drastically reduce the number of automotive crashes and fatalities annually. In addition, the inclusion of vehicle-to-pedestrian (V2P) communication systems could further reduce fatalities, especially among vulnerable road users, such as pedestrians and bicyclists. According to the National Highway Traffic Safety Administration (NHTSA), the top 5 crash scenarios involving pedestrians account for 91% of all fatalities. Relatedly, 88% of the top 5 crash scenarios are addressable with V2P-based pedestrian safety systems.[35]

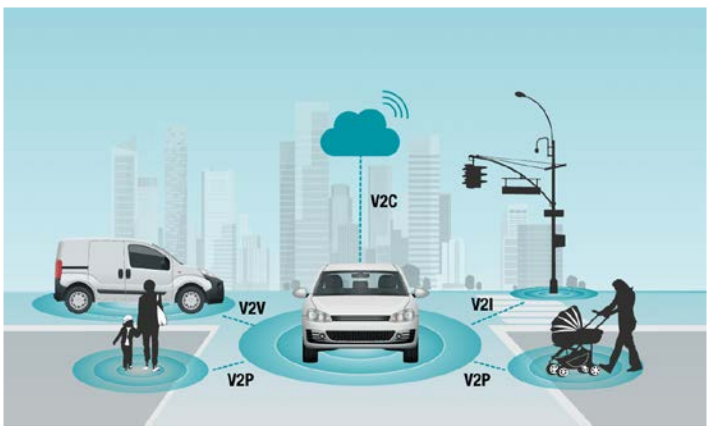

Figure 5: By connecting the various modes of transport with wireless safety communication, V2X can identify conflicts and reduce collisions, improving the safety of all modes; Source: Texas Instruments

Vehicle to everything (V2X) connectivity allows devices to automatically communicate pertinent information about a device's travel, such as speed, bearing, brake activation, or traction control activation, to other devices within the area. This data sharing allows advanced vehicle communication systems to coordinate actions amongst the various connected users of the roadway system. Integrating connected technology and automated devices, such as AVs, can potentially help the overall traffic network run more safely and efficiently, potentially reducing travel times and emissions while improving network reliability.

Among the types of communication is vehicle-to-pedestrian (V2P), leading to programs like the Mobile Accessible Pedestrian Signal System, the Pedestrian in Signalized Crosswalk Warning, and the safe intersection crossing project at Carnegie Mellon University (CMU). These projects are discussed further in the Accessible Streets section of this literature review.

CONSIDERATIONS

Automation, and AVs in particular, could significantly transform transportation accessibility. Securing America's Future Energy (SAFE), a non-partisan organization committed to innovations in transportation, indicated that widespread deployment of accessible AVs could enable an additional two million people with disabilities to pursue employment in the labor force. For this benefit to be realized, however, the vehicles must be accessible. Disability advocates stress their concerns how technology has often prioritized innovation first and accessibility second.[30] The broad adoption of a universal design approach – designing vehicle controls to be usable by all people, to the greatest extent possible – would benefit a more varied user base and expand the market. Vehicles built under accessibility and universal design principles are likely to offer improved access for passengers and cargo ingress, egress, and storage.[36]

Vehicle redesign and features: The potential to remove equipment, such as the driver's cockpit, steering wheel, and pedals from AVs, could open up additional space in the vehicle's interior without requiring significantly increases to the dimensions of the frame. As a result, AVs could be redesigned to accommodate a wider range of users. Toyota's e-Palette, for instance (depicted to the right), reimagines the traditional vehicle and is designed to accommodate up to four wheelchair-bound passengers along with other standing passengers. The vehicle also "includes handrails and seats that are easy to use regardless of height; … features floor, trim, seats, and other components with color contrasts that assist people with color-blindness; … [and] is equipped with large sliding doors, low floors, electric ramps, and an Arrival Control system for use when approaching destinations to enable passengers, including those in wheelchairs, to enter and exit quickly and easily." Designing AVs with features like these, that accommodate individuals with disabilities, can potentially make the vehicles more accessible to a wide range of users – for instance, people traveling with luggage, strollers, heavy groceries, and the like.[37]

Figure 6: Toyota's e-Palette, an electric AV designed to accommodate up to four wheelchair-bound passengers with additional riders; Source: Toyota

> *Note*: When considering how driverless vehicles may be redesigned, associated standards may need to be modified to meet the new needs and capacities of evolving technology. Perhaps certain vehicle features may become obsolete with the potential for safer operation and fewer accidents. However, there will also likely need to be new features and policies surrounding how driverless vehicles communicate with other road users. Just as the vehicles should be accessible to passengers, it is similarly important for them to engage accessibly with those outside the vehicle (for example, via alerts and signals that can be understood by everyone). For AVs to safely integrate into a heterogeneous traffic environment, associated policies and educational initiatives will be necessary.

Diverse perspectives: While some AV developers actively reach out to the disability community for input and feedback while prototyping designs, all AV developers should be encouraged to seek out feedback from diverse users. Similarly, hiring engineers with diverse needs and experiences (individuals representing different socioeconomic backgrounds, ages, cultures, and abilities) can help to ensure that the technologies produced are equipped to be accessible to all. In addition, the accessibility needs of individuals with cognitive disabilities need to be addressed as well. Integrating ease of use into the new technology, including an accessible, adaptable, and supportive user interface, could make it easier for people on the autism spectrum, individuals with intellectual disabilities, and older adults who may have less familiarity with recent technology, to comfortably use automated systems.[30] Collaboration between the various stakeholders – developers, public sector, the disability community – is important to develop a barrier-free AV solution.

Many disability advocates have said: “Nothing about us without us.” There is both an eagerness to be engaged in the development and rollout of these technologies and a fear that if they are not at the table, the systems or devices that go to market may not be fully accessible.[38]

Diversity is not only important for design input, but for training data as well. Most automated systems utilize artificial intelligence (AI) for various functions. This AI is trained in its decision making by using large datasets for training, studying how decisions were made previously and applying that decision making process to new data. The AI programmer may not realize this inherent bias in the data, due to the programmer’s race, gender, socioeconomic status, or the like. This training data may contain biases, likely unrecognized by the programmer but implemented by the trained AI. These inherent biases must be kept in mind, and counteracted if identified.[39,40]

Education and training: AV technology is in its infancy. Not many individuals have used this emerging technology. Due to this unfamiliarity, there are different expectations and concerns surrounding the use of AVs. Much like some customers of Tesla’s Autopilot system may assume it can drive anywhere for them, AV passengers may need training to understand how the AV will operate, its movements, and its communication with the passengers. To address this concern, AV developers could collaborate with public and private transit agencies to orient and train potential AV passengers on how to use and what to expect from the technology.

Use-cases: The majority of AV development is occurring in more populated, urban areas, and due to the implementation of the current technologies, most of the focus of future deployments will continue to occur in more commercially viable areas. Individuals who live in more rural areas already have far fewer transit options, creating a barrier to accessible, affordable transportation. While the simple landscape and less-congested roadways could have a positive impact to AV deployment, the lack of communication infrastructure could lead to challenges in the vehicle’s summoning and operation. Also, the lower population density means trips are likely longer, likely leading to increased costs per trip as well as more “deadhead miles,” when the vehicle is transiting to and from passenger rides.[30] These deadhead miles could be used by AV deployers to offer transport services of goods, such as package or grocery delivery.

With respect to considering dynamic applications for AVs: Toyota, for instance, has mentioned they envision that their electric AV, “e-Palettes,” designed to be “scalable and customizable for a range of Mobility as a Service businesses”, will serve a “variety of functions, from typical mobility services like ride-sharing and carpooling, to less-typical purposes like serving as mobile office and retail space, medical clinics, hotel rooms, and more.”[41] Moving forward, innovative ways to leverage AVs and time spent en route for various purposes could transform the market case/s for AVs and their role in the transportation ecosystem.

Technical challenges: Another factor to consider is the safety and accuracy of AVs. To operate safely, AVs always need to know their location, often utilizing the Global Positioning System (GPS) satellites and cellular radio towers. While the accuracy can be very precise in ideal conditions, there is a possibility for error, such as when GPS signals are blocked with urban canyons, or cellular reception is weak in rural areas.[42] In addition, locations with a single address for multiple buildings, such as a college or a corporate campus, can create challenges when summoning an AV. This lack of reliable location information could result in safety issues for individuals with disabilities.

Security: Passenger security, data privacy, and cyber security, as well as associated questions pertaining to liability are all also important points for consideration as automated systems continue to be developed. How should driverless vehicles and associated applications be designed so that passengers, potentially sharing rides with strangers (since a shared/fleet model, as opposed to private ownership, is likely how AV would rollout),[43] feel safe? What happens if there is a problem with the vehicle or a passenger en route? What type of personal data will need to be shared for the full range of users to be able to book rides that meet their needs? How resilient and reliable are these vehicles and devices? Since the degree to which riders feel that they, their belongings, their information, and their trip are safe will impact behavior, these considerations are critical to the adoption/utilization of automation for mobility.

Barrier-specific Commentary: Automation

Mobility Barrier	**Select Comments**
Physical limitation or disability	• AVs have the potential to provide real-time, on-demand, personal transportation to everyone, including individuals unable to drive. • If the need for a driver is removed, AVs could be redesigned to have a more accessible layout without significantly changing the footprint of the vehicle. Vehicle redesign implementing universal design guidelines could help make automated technology accessible to all. • Automated wheelchairs, like what is being developed by Whill, can potentially improve mobility off-road (such as indoors or around parks).
Cost	• Rolling out AVs via fleet deployment, as opposed to private ownership, could reduce the costs associated with using these vehicles. • As the technology matures and the costs of manufacturing AVs goes down, the cost of using automated services will likely decrease as well.
Coverage	• AVs can potentially provide a dynamic, on-demand transportation option in a variety of environments, from retirement communities to transit deserts.
Safety/Security	• It is expected that AVs and CAVs could significantly reduce collisions and fatalities, helping to make the transportation network safer. • Moving forward, it is important that AVs be able to effectively and accessibly communicate with passengers and other road users. • People need to feel that AVs are safe and secure for mass adoption. To this end, cybersecurity, data management, effective policy, and associated educational initiatives are important.
Awareness	• As more automated technologies come to market, associated educational and outreach initiatives will be necessary.
Technical limitations	• There should be a variety of options available for ride reservation – smartphone application, calling, website, etc. • There should be a variety of options available for sending and receiving information regarding service, for trip payment, etc.
Design/Upkeep	• Broad AV deployment could lead to road design changes, such as different road sign/marking needs or a reduction in the space necessary for the safe operation of vehicles (for instance, a lane dedicated to AVs may not need to be as wide and/or vehicles may be able to drive closer together). These changes could potentially create opportunities to increase the amount of public space available to pedestrians and other transportation modes. • With respect to AI associated with automated systems: whenever a system uses data and/or predicative analytics to make decisions about performance, distribution of service, etc. the possibility of bias in training datasets must be kept in mind. Without diverse, representative data input and algorithms, associated output and decision-making may not be representative or equitable.

MOBILITY ON DEMAND

The emergence and growth of on-demand, shared mobility services – such as Uber, Lyft, and the wide array of micromobility programs (from electric scooter shares to bikeshares) – has significantly transformed the transportation ecosystem over the past several years and is actively shifting the way travelers approach mobility. These new platforms and their associated partnerships and pilot programs can be referred to under the umbrella term, Mobility on Demand (MOD). Through these new, dynamic platforms, there is potential to help fill gaps in transportation coverage, connect commuters with existing transit services, efficiently respond to specific/personalized user needs, and aid in the planning of multimodal trips.

Figure 7: Image of new approaches to mobility; Source: UCL Energy Institute

WHAT IS MOD?

The FTA defines MOD as the "integrated and connected multi-modal network of safe, affordable, and reliable transportation options that are available and accessible to all travelers."[44] This network includes not only traditional transit options, but also the range of shared mobility services that can be leveraged to flexibly meet user need. Key shared mobility services, as defined by the Society of Automotive Engineers (SAE International) include:

- **Ridesourcing:** *Ridesourcing services are prearranged and on-demand transportation services for compensation in which drivers and passengers connect via digital applications. Digital applications are typically used for booking, electronic payment, and ratings.*
    - (*Note*: Ridesourcing passengers are generally able to request a private ride. However, some ridesourcing platforms do offer the option to rideshare. Ridesourcing is sometimes also referred to as ride-hailing.)
- **Ridesharing:** *Ridesharing (also known as carpooling and vanpooling) is defined as the formal or informal sharing of rides between drivers and passengers with similar origin-destination pairings. Ridesharing includes vanpooling, which consists of 7 to 15 passengers who share the cost of a van and operating expenses and may share driving responsibility.*
- **Microtransit:** *Microtransit is a privately or publicly operated, technology-enabled transit service that typically uses multi-passenger/pooled shuttles or vans to provide on-demand or fixed-schedule services with either dynamic or fixed routing.*
- **Carsharing:** *Carsharing offers members access to vehicles by joining an organization that provides and maintains a fleet of cars and/or light trucks. These vehicles may be located within neighborhoods, public transit stations, employment centers, universities, etc. The carsharing organization typically provides insurance, gasoline, parking, and maintenance. Members who join a carsharing organization typically pay a fee each time they use a vehicle.*
- **Bikesharing:** *Bikesharing provides users with on-demand access to bicycles at a variety of pick-up and drop-off locations for one-way (point-to-point) or roundtrip travel. Bikesharing fleets are commonly deployed in a network within a metropolitan region, city, neighborhood, employment center, and/or university campus.*
- **Scooter sharing:** *Scooter sharing allows individuals access to scooters by joining an organization that maintains a fleet of scooters at various locations. Scooter sharing models can include a variety of motorized and non-motorized scooter types. The scooter service provider typically provides gasoline or charge (in the case of motorized scooters), maintenance, and may include parking as part of the service. Users typically pay a fee each time they use a scooter. Trips can be roundtrip or one way.* [45]

A range of mobility service providers have entered the MOD sphere to offer these shared transportation options. Some examples of companies who have operated and/or are actively operating in each of the above-mentioned spaces are listed below for reference.

MOD Mode	**Example Vendors/Services**
Ridesourcing	Transportation Network Companies (TNCs), such as Uber and Lyft; There are also ridesourcing services that are designed to meet specific needs. For instance, HopSkipDrive and Zūm are ridesourcing options designed to transport children, while Moovmo is a service primarily designed to accommodate people requiring accessible transportation.
Ridesharing	Scoop, Waze Carpool, and Hytch; pooled options within Uber and Lyft, respectively UberPool and Lyft Line, are also examples of ridesharing
Microtransit	Via, DemandTrans, Transdev, and Ford Smart Mobility company, TransLoc[46]
Carsharing	ZipCar, SHARE NOW (formerly Car2Go), Free2Move Carsharing, Enterprise CarShare, Maven, Turo, and GetAround
Bikesharing	Capital Bikeshare, Lime, JUMP (by Uber), Pace (by Zagster), Gotcha, BCycle, Divvy, BayWheels (by Lyft), and Bublr; there are also various bikeshare programs, like "Metro Bike Share" in Los Angeles, that come about through pilot programs.
Scooter sharing	Lime-S (by Lime), Razor, Skip, Spin (by Ford), Bolt, Lyft, Bird, JUMP (by Uber), Gotcha, VeoRide, Ojo, and Blue Duck

While the above-mentioned modes have become quite established, with deployments and pilots across the country, new modes are still evolving as well. For instance, the District Department of Transportation (DDOT) recently launched a four-month moped sharing pilot program in Washington D.C.[47]

The evolution of MOD and shared mobility services has the potential to help alleviate a range of accessibility barriers – increasing the range of timely, customizable, accessible, affordable transportation options on the road. These services and their associated pilot programs can, for instance, potentially help to:

- Provide new, dynamic alternatives to driving single occupancy vehicles, potentially helping to alleviate congestion in some situations
- Bridge first/last mile transportation gaps and connect riders with existing transit services
- Offer more cost effective, timely paratransit service
- Improve options for non-emergency medical transportation
- Meet the transportation needs of seniors, veterans (and military families), etc.
- Provide increased mobility on university campuses and in downtown areas
- Aid mobility during special events: emergencies, holidays, sports events, etc.
- Connect those in need with rides to jobs, groceries, and other fundamentals
- Make the process of trip planning and traveling more effortless and worry-free

Figure 8: Evolving micromobility options, including electric scooters and bikes; Source: [Porsche Consulting]

(*Note:* While the above list outlines some of the potential benefits of MOD, it is also important to keep in mind that not all modes are equally well suited to provide every benefit – in some cases, one mode may provide a specific benefit, while another may not. For instance, while carpooling may help to alleviate congestion in urban areas, ridesourcing may not. The characteristics of the area where new services are deployed and policies pertaining to operation (for instance regarding where and how a mode may be used, parked, on/off-boarded, etc.), among other factors, may impact whether a given service in fact has a net positive or net negative impact on mobility. Tests of shared mobility services with various parameters and in various environments are ongoing.)

Through partnerships with local government and transit agencies, new mobility options can be (and are being) leveraged along with existing services to offer inclusive, multimodal programs with characteristics that aim to support accessibility – fare options for users of various needs, flexible ride booking and payment, integrated platforms for trip planning, and a rage of travel choices and vehicles that can be selected on-demand to meet user needs.

SHARED-MOBILITY FOR CONGESTION MITIGATION

Congestion (and the resulting oversaturated demand for parking) in metropolitan areas presents a pervasive barrier to mobility – making trip times longer and more unpredictable. According to 2016 American Community Survey (ACS) data, over 76 percent of Americans drive to work alone every day. "Considering that ACS counted 150 million workers in 2016, that's at least 115 million cars and trucks hitting American streets every day."[48] While many Americans take public transit, sometimes the trip time, distance to a stop, or availability of a fixed-route service may limit the viability of using these services in place of a privately owned vehicle. However, shared mobility services, such as rideshare and micromobility options for instance, offer on-demand alternatives.

Rideshare: On-demand carpool services, like Lyft Line and UberPool, operate across the country and offer a way to travel door-to-door with other commuters traveling on similar routes. In addition to there being more options now for those interested in ridesharing, there are also some programs that aim to incentivize carpooling. For example, the Bay Area Council in San Francisco partnered with Nashville-based carpooling app, Hytch, as part of its transportation demand management coalition, in order to offer rewards to those who chose to commute together.[49] Programs developing and testing new approaches to incentivize ridesharing, may help reduce the number of people choosing to travel by driving alone.

Figure 9: Commuters carpool and collect rewards for ridesharing using the Hytch app; Source: [Tennessean]

Microtransit: Microtransit programs can offer flexible bus service, providing (for example) dynamic corner-to-corner transportation between areas within a designated zone. For instance, in June of 2019, Montgomery County Department of Transportation (MCDOT) launched microtransit service, "Ride On Flex," in partnership with Via. Through this program, riders can request rides on 11-passenger, wheelchair-accessible busses for no more than $2. As Montgomery County Executive, Marc Elrich, stated: "Flex service holds tremendous promise not only for taking cars off our roads, but also improving equity for residents who need an affordable solution for getting around quickly."[50] These dynamic buses can fill gaps in the transportation system while also helping to reduce cost-related barriers to mobility.

Micromobility (electric scooter share, bikeshare, etc.): The National Association of City Transportation Officials (NACTO) defines shared micromobility as a term that "encompasses all shared-use fleets of small, fully or partially human-powered vehicles such as bikes, e-bikes, and e-scooters."[51] (Note: the "e-" in e-bike or e-scooter refers to "electric.") Bikeshare systems, and now scooter share systems, have gained popularity over the past several years. NACTO reported that: "in 2018, people took 36.5 million trips on station-based [bikeshare] systems and 38.5 million trips on shared e-scooters," and e-bikes "emerged as a popular option, accounting for 6.5 million trips in 2018 (6 million in dockless systems and 500,000 in station-based systems)." Additionally, "since 2010, people have taken 207 million trips on shared bikes and e-scooters."[51] With their rise in deployment and ridership, many local governments are working together with micromobility service providers to offer locals and tourists these new options to explore downtown areas without a car. For instance,

- In September of 2018, Arlington County, Virginia launched a shared mobility pilot project including dockless electric-assist bikes and electric stand-up scooters. According to the pilot evaluation report, there "was a total of 453,690 [shared mobility device] trips in Arlington County between October 2018 and June 2019." With respect to shifts in travel behavior as a result of the new mobility devices, the evaluation noted, for instance, that 32% of e-scooter riders reported that their scooter ride "replaced an automobile trip."[52]
- In September of 2018, the City of Santa Monica also launched its Shared Mobility Pilot Program in partnership with Bird, JUMP, Lime, and Lyft.[53] According to the pilot evaluation report, people most often used these devices "for short work-related trips (29%), recreation (26%), eating out (14%), to get to/from home (11%), and shopping (8%)."[54]
- Many other similar programs have launched throughout the country (in Montgomery County, Maryland,[55] Kansas City, Missouri,[56] Portland, Oregon,[57] etc.)

It should be noted that some micromobility deployments have encountered or created significant problems after rolling out. For instance, shared e-scooters and bikes ridden or parked on sidewalks have led to some safety-related concerns for pedestrians and accessibility concerns for members of the disability community. As a result, some areas have enacted associated bans or restrictions.[58] Many micromobility pilots, however, are now testing more controlled, regulated use of these technologies, with the aim of more safely incorporating these dynamic modes into the existing transportation environment. (Cities, such as Richmond[59] and San Francisco,[60] for example, after initially banning scooters, allowed for structured relaunch by permitted operators via pilot programs. Permitting to participate in these pilots may include caps on the number of devices permitted, as well as requirements to meet "standards for safety, equity and accountability.")[61]

While studies regarding the impact of micromobility on congestion are ongoing, and while the potential benefit of shared scooters and bikes may vary based on the profile of the area where they are deployed, micromobility can provide a quick, on-demand alternative to driving for short trips. With 60% of trips in the U.S being less than 5 miles long,[62] this efficient, healthy, and (relatively) environmentally-friendly way for people to explore downtown areas and reach their destinations without a car, may help mitigate congestion.

By providing accessible alternatives to driving alone, shared service platforms and device deployments can help the transportation network run more smoothly yet continue to meet a range of travel needs.

MOD AND FIRST/LAST MILE ACCESSIBILITY

In addition to serving as complete replacements to previous travel options (e.g. ridesharing or scooter sharing, for instance, can be used to completely replace a solo car ride), MOD services can also be leveraged to help improve first/last mile accessibility and connect riders to existing transportation services, such as public transit.

Some commuters may want to use a bus or train to, for example, avoid traffic or parking. However, if the bus station is too far away or otherwise inaccessible, they may forgo transit. Below are some examples of shared mobility deployments and public-private partnerships (P3s) leveraging these services that are helping to bridge first/last mile transportation gaps and improve access to existing, fixed-route transit systems:

Microtransit: Microtransit services can be used to flexibly extend the coverage the existing transportation network. Various transportation authorities have partnered with microtransit vendors to offer new services that provide more dynamic access to bus stops, train stations, or transit hubs. For instance:

- Tri Delta Transit and TransLoc partnered for "Tri MyRide" microtransit pilot in Contra Costa County, California. Launched in June of 2019, this microtransit program enables travelers within the Hillcrest/Antioch or San Marco/Pittsburg Bay Point Bay Area Rapid Transit (BART) service areas to request $2, wheelchair accessible rides to local BART stations or other destinations within the service area.[63]
- LA Metro and Via partnered to launch a microtransit pilot in Los Angeles, California. This yearlong pilot, rolled out in January of 2019, "allows Metro riders to hail shared rides to or from three stations: Artesia, El Monte and North Hollywood Stations" and aims to "make it easier for riders to connect with [the] growing Metro system." Additionally, Metro is subsidizing the cost of rides to make the service more affordable. "Riders who are registered with Metro's low-income fare program, LIFE, can ride for free. Riders who input TAP cards during account creation will ride for $1.75 and riders without TAP cards can ride for $3.75."[64]

Figure 10: Tri MyRide microtransit service connecting riders to BART stations and local destinations; Source: Tri MyRide

- The Capital Metropolitan Transportation Authority (Capital Metro) partnered with Austin-based rideshare service provider, RideAustin, to offer free, on-demand rides to select bus stops in Austin, Texas. Through this six-month pilot program, travelers could request free rides to/from one of two local Capital Metro bus stops. The partnership was designed to help fill gaps in the coverage of public bus service.[65]
- SouthWest Transit, in partnership with Ridecell, began operating microtransit service, "SW Prime," in 2015. Through this program, riders can request on-demand curb-to-curb rides by calling or via app.[66] "Commuters traveling as far as 20 or 30 miles into Minneapolis for work would pay a $4 fee and transfer for free to Southwest Transit's regularly scheduled bus service that goes from the suburbs to the downtown."[67]


Figure 11: MOD partnerships can enable riders to book rides to connect with transit; Source: Community Impact Newspaper

Ridesourcing: Partnerships with ridesourcing services can also help to make transit networks more accessible and promote travel that incorporates existing public transportation services. Local government and transit agencies across the country have teamed up with ridesourcing providers to help make it easier for riders to reach and utilize transit. For instance:

Figure 12: Partnership between Lyft and the City of Phoenix to improve first/last mile access to transit; Source: [ABC15]

- The City of Phoenix partnered with Lyft to launch the "[First Mile Last Mile]" campaign in October of 2017. This pilot program offered commuters discounted rides to or from local bus stops.[68]
- Five Florida cities (Altamonte Springs, Lake Mary, Longwood, Maitland, and Sanford) formed an inter-city partnership with Uber. Among other features, through this pilot Uber rides starting or ending at a SunRail commuter rail station within one of these 5 cities would be up to 25% off.[69]
- Ohio's Greater Dayton Regional Transit Authority (RTA) formed partnerships with both Lyft and Uber for "[RTA Connect On-Demand]." Among other features, this program enables riders to book free, on-demand rides to RTA transfer points, which will connect them to RTA fixed-route service.[70]
- In August of 2019, GoTriangle, the Research Triangle Regional Public Transportation Authority in the Research Triangle region of North Carolina, partnered with both Lyft and Uber "to provide subsidized rides in between bus stops and the many offices and other businesses throughout RTP." Through this partnership, GoTriangle will pay up to $10 for bus riders to take Lyft or Uber to their destination within RTP.[71]

Through these programs, public entities aim to make it easier and more affordable for people to access local transit, leveraging evolving services to improve existing mobility options.

MOD AND ACCESSIBLE MOBILITY FOR SPECIFIC USE CASES

As MOD has evolved, an increasing number of tailored services, partnerships, and use-cases have emerged. To illustrate the range of ways that MOD can be leveraged, and already is being applied, to improve mobility for users with specific needs, below is a list of some areas where shared services are changing approaches to mobility, as well as associated examples.

Paratransit: Various transit authorities are working with on-demand mobility services providers to offer more timely, convenient, cost effective paratransit service. For instance:

- The Massachusetts Bay Transportation Authority (MBTA) partnered with ridesharing companies Uber, Lyft, and Curb to offer on-demand transit service to [RIDE] customers. (The RIDE is MBTA's paratransit service.) This pilot offers shorter wait times, same-day booking, and cheaper prices, as seen in the

Service Comparison

Service	THE RIDE	Pilot Program
Price	$3.35 or $5.60 for premium trips	As low as $2.00
Booking Timeframe	At least 1 day in advance	On demand, instant request to dispatch
Day-of Wait Time	30-minute window	As low as 5 minutes in core service areas
Trip Reservations	By phone	Via smartphone app (Uber, Lyft, Curb) or phone call (Lyft and Curb only)

Figure 13: A comparison between MBTA's paratransit service available originally vs. through the MOD pilot program; Source: MBTA

service comparison in Figure 13.[72]

- RTA partnered with Ford Motor Company to offer Ford GoRide Health (GoRide) on-demand paratransit service in Dayton, Ohio. Through this partnership, beginning in May of 2019, wheelchair accessible rides can be ordered on-demand to help connect individuals with disabilities with healthcare and other services.[73] As stated by the CEO of GoRide Health, Minyang Jiang: "GoRide offers an on-demand option that is useful for customers with disabilities or that require an accessible vehicle. All GoRide drivers are HIPAA compliant and professionally trained to safely assist passengers."[74]
- Dakota County has partnered with Lyft to offer flexible, on-demand rides to individuals with disabilities in Dakota County, Minnesota. Through this pilot program, "eligible individuals may use Lyft credits, paid through Medicaid waivers, to order rides to/from work and community activities."[75] According to the Shared-Use Mobility Center (SUMC), survey responses and feedback indicated that after a month of use, as a result of the pilot:
    - *63% of individuals were able to work more hours and/or days;*
    - *69% of individuals' friends and family no longer needed to drive them;*
    - *88% reported that their transportation was more reliable; and*
    - *3 individuals were able to get a new job.*[76]

These results would suggest notable improvement in the quality of the mobility that eligible paratransit users had access to as a result of the partnership.

Non-emergency medical rides: "For the 3.6 million Americans who do not obtain medical care due to transportation challenges, access to healthcare is not only a financial issue, but also a matter of logistics."[77] A range of programs and collaborative initiatives have emerged that tie in shared-mobility providers with the aim of improving non-emergency medical transportation. For example:

- Uber Health: Uber has developed initiatives aimed at reducing barriers associated with non-emergency medical transportation. The head of Uber Health, Dan Trigub has stated: "Via our HIPAA-compliant solutions, we are working to facilitate rides for patients who might not have access or the ability to use smartphones, and to improve access to care for patients with mobility issues."[78]
- Blue Shield of California has partnered with Lyft to launch "rideQ" in Sacramento, California. This pilot offers eligible members free rides to doctors' offices and healthcare locations, and aims to make it easier for patients to get the mobility they need to stay healthy.[79]
- Tennessee Carriers Inc. has partnered with Lyft to transport TennCare members as part of a one-year pilot program to provide on-demand non-emergency medical transportation.[80]
- Chesterfield County partnered with Uber and Goodwill of Central and Coastal Virginia to offer free treatment-related transportation to individuals trying to recover from opioid addiction. "The partnership provided transportation to access employment opportunities, job training, health care or even basic needs such as grocery shopping."[81]

Rides for the elderly: Services have developed that are specifically designed to alleviate transportation challenges that an elderly person may encounter. For instance: GoGoGrandparent is designed to enable users to order rides via Lyft and Uber without a smartphone, with rides monitored by 24/7 operators and alerts for emergency contacts.[82] Similarly, Lyft works with GreatCall, a Jitterbug medical alert and

Figure 14: MOD services tailored to specific user types (such as elderly individuals) can be leveraged to target unique needs for more accessible mobility; Source: Daily Caring

phone company, to offer a rideshare service for seniors. Through this service, users do not have to use a mobile application to schedule a ride. Instead, they can go on their GreatCall phone, type zero, and an operator will schedule the Lyft.[83] On-demand MOD services can help seniors (for instance, those who can no longer drive) continue to get around independently. Since the need to use an app to schedule rides may a hurdle for some seniors, platforms that offer alternate options for trip planning and ride booking are valuable to ensuring that no user group is left out.

Figure 15: Lyft initiative to improve mobility during an election; Source: Lyft

MOD can help to improve mobility in a wide range of other contexts as well. Micromobility pilots, carshares, and late-night ridesourcing programs, for instance, are helping to improve accessible transportation options in and around University Campuses.[84] MOD services are helping to expand ride options for veterans and on military bases,[85] and connecting people in need with access to groceries or the ability to travel to job interviews. [86,87] Shared-use mobility services also can serve as a means of safe, efficient mobility during special events where access to timely transportation may have historically been a challenge. For instance, ridesourcing partnerships have been formed to help during or after natural disasters,[88] elections,[89] holidays,[90] concerts,[91] sporting events,[92] etc. Moving forward, there are likely to be even more use-cases where dynamic, connected, on-demand options can help to improve mobility.

MULTIMODAL TRIP PLANNING

The expansion of integrated trip planning and payment platforms for multimodal, shared-mobility services is a notable mobility trend that offers the potential to make it easier for travelers to understand their mobility options and make informed, personalized travel decisions. Applications like Transit, for instance, aggregate service information pertaining to public transit and various shared mobility options in the area, enabling users to compare different services and plan multimodal trips. In the Wasatch Front region of Utah, for example, where the Utah Transit Authority (UTA) has partnered with the Transit app, "riders can now access real-time information regarding nearby bus and rail options. The app provides transit departure times, allows for real-time tracking, and enables users to receive route-specific push notifications. Transit's Go feature also offers step-by-step navigation and riders can use the app's Transit+ feature to get information on other modes – including Lyft, Uber, GREENbike, and Spin – for their first/last mile travel needs. Lyft and Uber rides can be booked and paid for within the app."[93] Seamless trip planning and payment can potentially make it easier for people to build trips that are more time and cost effective, leverage both new mobility services and existing transit networks, and meet their personal transportation needs and preferences.

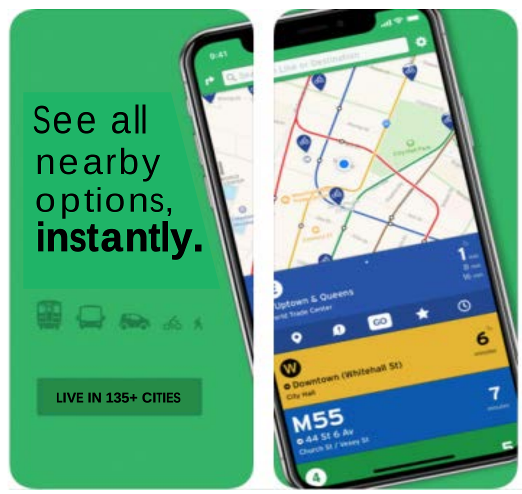

Figure 16: The Transit app, a platform offering integrated, multimodal trip planning and payment; Source: Transit App Inc.

CONSIDERATIONS

As the transportation ecosystem continues to develop and on-demand mobility services become perhaps increasingly integrated into the fabric of how people commute, access public transit, and travel around communities, it is important to keep various factors in mind:

Context/Use-case matters: While various MOD services potentially present opportunities to provide transportation benefits under the right conditions, if not rolled out with tailored consideration some services could also potentially exacerbate existing issues. For instance, with respect to congestion: while ridesourcing might be leveraged in suburbs or transit desserts to help connect commuters with existing transit services, thereby potentially reducing the need for those commuters to drive into a busy metropolitan area and contribute to congestion, it is also important to note that ridesourcing under other scenarios may contribute to congestion. For instance, according to a report by the San Francisco County Transit Authority in 2018, TNCs accounted for "51% of the increase in daily vehicle hours of delay between 2010 and 2016; 47% of the increase in vehicle miles travelled during that same time period; and 55% of the average speed decline on roadways during that same time period."[94] Furthermore, a recent California Air Resources Board (CARB) study indicated that over a third of the vehicle miles traveled by TNCs in California are deadhead miles – miles associated with "travel periods without a passenger in the car."[95] As a result, while additional research is needed, recent studies suggest that TNCs may have contributed to worsening congestion in San Francisco.[96]

> *Key Takeaway:* In some areas, certain modes may be better fits than others when trying to alleviate specific transportation barriers. Areas may have different characteristics and commuters may have different needs and travel patterns. As a result, various factors, such as whether a given mode in fact increases transit ridership or takes away from it (for instance), should be considered when trying to determine what mix of services and pilot programs may best serve a given transportation environment.

Affordability: In some cases, there is concern that on-demand services may reduce ridership on public transportation systems. While bus and train fares are kept somewhat low, private services like taxis have generally been notably more expensive. For MOD services to be accessible to all users, there must be affordable options for low-income users. To this end, many MOD programs and partnerships include discounted rates for eligible users – for instance, students or individuals participating in a state or federal assistance program. The cost of rides critically impacts the degree to which some travelers can (or cannot) utilize a mobility service. To reduce cost-related barriers to mobility, transportation services should have options available for users with different levels of financial need.

Flexible options for ride booking/payment: As mentioned when discussing MOD programs for the elderly, the options available for ride booking and payment can expand or limit the population able to use that service. Some users may not be able to use a smart phone -- they may not own one or they may not understand the associated mobile app. Similarly, when paying for rides, not all users may have a credit card. Systems that accept payment via a local transit card may help make it easier to seamlessly pay for rides, however, some users may need (or prefer) to pay for transportation with cash. According to a report by the Department of Labor, "many stakeholder groups expressed concerns about how to pay for accessible rides. Shared ride vehicle services are often not set up for payments from disability support sources, and many people using accessibility services may lack access to credit cards for payment. In Pittsburgh, for example, there are multiple payers (Veteran's Affairs, Vocational Rehabilitation, etc.) and a network of different funding mechanisms with different ways to access funds. There is a concern that non-government agencies providing transit services might not want to handle multiple payment structures."[30] Services that are designed considering multiple payment structures are likely to be more accessible for all users.

Availability of accessible vehicles: The availability of vehicles that can accommodate individuals with disabilities is important to the accessibility of transportation services. While some ridesourcing companies have received criticism for their lack of accessible vehicles, there are also programs working to improve the availability of accessible devices – such as microtransit programs utilizing a fleet of Wheelchair Accessible Vehicles (WAVs) or bikeshare programs that include adaptive bikes. (For example the Portland Bureau of Transportation partnered to launch Adaptive BIKETOWN, a bikeshare program in Portland, Oregon that includes handcycles, trikes, tandems, and more in order to increase biking access for people with disabilities).[97] Having accessible vehicles on the road will make it easier for a wider range of users to use MOD.

Safety: There are many factors to consider with respect to safety: Do riders feel safe when they travel on modes that incorporate a shared component? Do vulnerable populations have a way to access their ride and monitor their trip? Do on-demand MOD mobility devices and vehicles have safe places to operate and on-board/off-board without putting either the rider or anyone on the road or in the public right of way at risk? (For instance, while electric scooters have grown in popularity, there is concern about where the vehicles can be ridden and parked.) Is personal information secured when it is shared across integrated mobility platforms? To alleviate concerns and barriers, a variety of specialized services, in-app features, and pilots have emerged. There are, for instance, ridesourcing options that are exclusively available for transporting children, options where female riders can request female drivers, features that make it easier for riders to share their location to feel safe en route, and more. Pilot programs are also actively working to make MOD vehicle operation and parking safer for everyone. Feeling safe when using a service is vital to enabling use and promoting mobility. Moving forward, it may be necessary to update associated policy to accommodate the evolution of mobility and increasingly dynamic, multimodal transportation ecosystem.

Designing transportation programs and partnerships that take into consideration the needs of various groups and the characteristics of the area will help to make the transportation ecosystem more accessible for all as it continues to evolve with new, dynamic, shared, multimodal mobility services.

Barrier-specific Commentary: MOD

Mobility Barrier	Select Comments
Physical limitation or disability	• First/last mile service can help provide connections to traditional transit services for all users, potentially increasing transit use. • Partnerships with MOD providers can provide paratransit service to some users faster and cheaper than traditional paratransit service. • Deployment & integration of accessible devices (such as adaptive bikes) could open up new mobility options to individuals that may not have previously had convenient access to these services.
Cost	• Many MOD public-private partnerships aim to offer more affordable access to transit, paratransit service, or micromobility. Some programs include subsidized membership rates for qualifying users – such as lot income individuals or students. • Partnering with MOD service providers to offer lower cost services (such as on-demand paratransit) may, in some scenarios, help transit agencies to save money. This could potentially help to make additional resources available to allocate for other transportation-related needs.
Coverage	• MOD services can be leveraged to improve first/last mile access to local transit stops and/or help to extend the reach of transit (for instance, through partnerships for dynamic routing of transit vehicles). • MOD can help to provide a wider array of transportation options to areas that may have been underserved, such as transit deserts.

Mobility Barrier	Select Comments
Safety/Security	• Various MOD providers (such as Uber and Lyft) have developed programs and initiatives geared toward trying to make passengers feel safer en route. • Several MOD providers offer tailored services geared toward specific communities, such as elderly riders, children, etc. • As transportation-related platforms (for instance, related to trip planning, tracking, or booking) become increasingly integrated, issues related to information security should be considered. • Safety-related initiatives and policies (such as programs promoting helmet use), may help to increase safe micromobility ridership. • Road design and policies that encourage safe operation and parking of emerging transportation modes in a multimodal environment are critical for safe mobility for all. (Dedicated TNC loading/unloading zones and e-scooter parking areas, for instance, can help sidewalks and roads remain safe and accessible for other road users.)
Awareness	• For MOD services and benefits to reach a wider audience, effective outreach initiatives and service advertisement is important. • People need to be aware of their service options to use them.
Technical limitations	• Some travelers may not have access to, for instance, a smartphone or credit card. Flexible options for trip planning and payment are important in order programs to be inclusive.
Design/Upkeep	• Some MOD services may be able to help reduce congestion by proving alternatives to traveling via single occupancy vehicle. This could potentially enable the transportation network to function more efficiently, helping to mitigate time-related travel barriers. • How mobility programs are designed – how vehicles are distributed, for instance – impacts accessibility. When planning or approving programs it may be worth considering what data/factors are involved in the decision making process. For a service to be equitable and accessible, it is important to identify and mitigate potential gaps or bias in information.

ACCESSIBLE STREETS

INTRODUCTION

Street design generally prioritizes one thing above all: vehicle throughput. Volume/capacity ratio and intersection level of service for vehicles are often the guiding metrics that determine the designs of roadways and intersections.[98] This often translates to placing as many travel lanes into the available real estate as possible, with intersections dominated by asphalt. This design philosophy, in turn, provides less space for alternative forms of transportation, like walking, bus lanes, emerging micromobility options like scooters, or even curbside drop-off space.

Prioritizing the throughput of vehicles above alternative forms of transport, however, may create mobility barriers for pedestrians and other road users. For instance, narrow sidewalks may discourage walking, lack of bike lanes may discourage bicycling, and limited access to bus stops may discourage transit use. While vehicle throughput is important, it may be worth reconsidering street design to promote accessible mobility for all -- particularly in areas with significant mixed-mode transportation, such as urban cores of cities.

COMPLETE STREETS

Complete Streets is a transportation policy that encourages safe, convenient street design that supports mobility for all users, regardless of their ability or mode of transportation. The concept of Complete Streets has continued to evolve as mobility options are introduced, but fundamentally involves designing street cross-sections for the wide array of road users, not just automobiles. This policy promotes safer paths for all modes of transport, potentially reducing congestion and injuries amongst all modes served.[99]

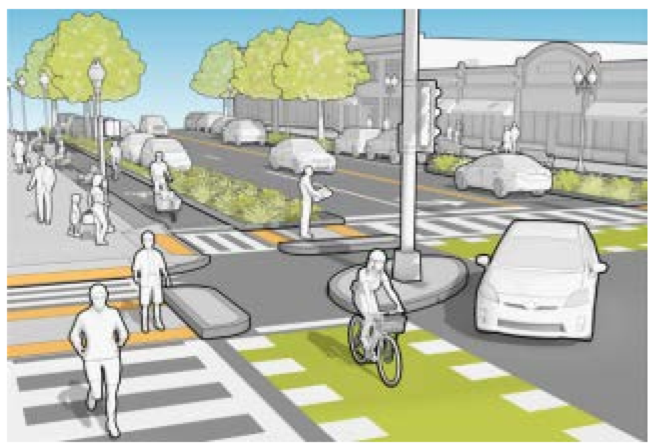

Figure 17: Elements of a protected intersection; Source: [MassDOT]

The typical Complete Streets cross-section designates space, sometimes separated by barriers, for different modes of transport. For example, Complete Street roads may include wide pedestrian sidewalks, protected intersections, travel lanes for automobiles, and/or separate bike lanes. With new modes of transport, such as micromobility options like scooters, gaining shares of ridership, some right-of-way may need to be introduced for their use. Additional design elements to encourage alternative modes can include features to encourage pedestrian travel, like wider sidewalks, plazas, mid-block crosswalks, raised crosswalks, curb extensions, or median islands; barriers separating bicycle facilities from other modes, like paint, pylons, or curbs; and traffic calming measures that are designed to reduce vehicle speeds, such as speed humps, chicanes, narrowing the painted lanes, and even planting trees next to the road.[100]

Complete Streets policy offers knock-on benefits including:

- **Improved safety for all transport modes**. As an example, by providing separate bicycle facilities, cyclists are less inclined to ride on sidewalks (improving pedestrian safety) and motor vehicle lanes (improving the safety of cyclists). Dedicated lanes keep transit vehicles out of congested general-purpose lanes, improving on-time performance.
- **Societal health benefits**. Providing a safe space for transit riders can help improve public health. The Centers for Disease Control and Prevention (CDC) recommends adopting a Complete Streets policy as a strategy to prevent obesity,[101] while the National Conference of State Legislatures identifies Complete Streets as the most effective policy for encouraging bicycling and walking.[102]

- **Environmental benefits.** Safe transportation options that encourage walking and cycling can reduce the number of people that take an automobile to their destination, reducing the number of cars on the road, congestion, and net vehicle emissions.
- **Improved utilization of the public right-of-way**. People commuting by bus or bicycle take up significantly less space on the road than if they were to commute via single-occupant vehicles. Designing transportation infrastructure to support mobility options that transport users more efficiently can improve the entire transportation network.
- **Cost savings for individuals**. Transportation is the second-largest expense for the average American, behind only housing. This high expense is driven by not only the cost of the vehicle, but fuel, maintenance, licensing, and insurance. Walking, bicycling, transit, and other alternatives to the automobile are often more economical transportation options, reducing their expenses.

A project in Orlando, Florida, provides an example of how a Complete Streets philosophy can improve safety for all pedestrians. Curry Ford Road was a five-lane arterial roadway that had a history of speeding and car accidents involving pedestrians and cyclists. A lane reduction, or "road diet," was applied, reducing the five-lane road segment to three lanes. The two removed automotive lanes were replaced with pedestrian refuges at crosswalks and delineated bicycle lanes. Although the project was initially met with resistance from automotive users, each of these measures are proven to improve safety for all users, shown by the Federal Highway Administration to reduce crashes.[103]

The potential deployment of AVs, connected vehicles (CVs), and connected automated vehicles (CAVs) into the national auto fleet may further drive opportunities to redesign and reimagine roads under a Complete Streets philosophy. With enough AV national fleet penetration, it may be possible to safely reduce lane width, especially if AVs are provided an exclusive travel lane. This reduction could be repurposed to provide additional right-of-way to other forms of transportation. Additionally, as CVs and CAVs potentially become a ubiquitous part of the national auto fleet, the right-of-way used by traditional traffic control, such as turn lanes, traffic signal controller cabinets, and signal poles, can be reclaimed for other purposes, such as sidewalks.

CURB MANAGEMENT

Curb space is premium real estate in urban areas – space managed by cities that is in demand for many disparate uses. Most curb space in urban areas is used for travel lanes or parking. This often means that other short-term uses, such as taxis or TNCs that, while still using an automobile, reduce the demand on parking. As an example, the city of Houston has partnered with app based TNCs to create rideshare parking zones. The current zones include restaurants and nightclubs, businesses that are typically active during the evening and late-night hours. The curb space is used by delivery vehicles during the day, then converted to TNC pick-up and drop-off zones during evening hours. When users request a ride from within the zone, they are directed to the loading zones to retrieve their ride.[104]

Further, the rise of online shopping puts additional demand on curb space. The ability to have everyday essentials, such as groceries, ordered and delivered without leaving home reduces the need for personal transport, including for individuals with disabilities. While some areas include short-term parking space for deliveries, if there is no available space at the curb, delivery vehicles may double-park, trapping vehicles on the curb and blocking normal vehicle traffic in the travel lanes. This increased demand should lead to new regulations on curb space.[105] In addition, the Open Streets movement takes the idea of opening spaces for pedestrians even further by closing streets to vehicles, allowing vendors to set up demonstrations, restaurants to set up outdoor seating, municipal governments to have education and outreach, and similar activities.[106]

Further into the future, as vehicle connectivity and AV adoption continues to increase its share of the national vehicle fleet, there will likely be opportunities to offer dynamic curb use regulations. For example, time-of-day regulations could be applied, allowing parking overnight, vehicle traffic during peak commuting hours, restaurant seating during meals, and pedestrian plaza space during weekend festivals. Connected vehicles could communicate with infrastructure to determine parking or loading zone restrictions in real time, while AV-specific signage could communicate additional information like curb use restrictions and schedules.[105]

PEDESTRIAN PATH MAPPING

Existing wayfinding tools, such as MapQuest or Google Maps, provide detailed turn-by-turn directions to users, whether walking, bicycling, driving, or using public transit. However, the wayfinding algorithms within these popular applications assume that the user is able-bodied and can cross at any intersection or walk adjacent to any roadway, whether a sidewalk exists or not. This creates difficulties for wheelchair users and people with visual impairment; marked crosswalks provide a visible route indication to pedestrians, and wheelchair ramps provide safe and easy access from sidewalks to crosswalks. If wayfinding tools direct people along paths comprised of only roadways, it frustrates and complicates their use for users with disabilities.

Figure 18: The pathMet device is a sidewalk profiling tool that measures compliance with ADA guidelines to provide accessible wayfinding for all; Source: pathVu

PathVu is developing a surface profiler called pathMet, a manually propelled device that identifies conditions along pathways and sidewalks. PathMet uses laser sensors and other tools to map and measure compliance of sidewalks and trails for current Americans with Disabilities Act guidelines, such as tripping hazards, cross slope, running slope, roughness, and level change. This collected data can be used by wayfinding applications to assess the path's accessibility, and cities can use the data to prioritize maintenance scheduling to sidewalks and other pedestrian paths in most need of rehabilitation.[107]

PathVu is also utilizing the collected pathMet data for pathVu Navigation (formerly AccessPath), a wayfinding app for wheelchair users and people with visual impairment. This tool can guide users along routes tailored to their mobility preferences. PathVu is partnering with the University of Pittsburgh, Fine Humans, and CivicMapper to develop the app. In order to assist both wheelchair users and people who are blind or visually impaired (communities that require such unobstructed routes), pathVu Navigation uses pedestrian wayfinding algorithms that feature only those networks of sidewalks, pathways, and crosswalks that are connected. pathVu Navigation will utilize geographic information provided by ArcGIS for its base map and wayfinding, and will utilize the high-fidelity data collected via pathMet. pathVu Navigation integrates pathway quality, a customizable user interface, and user preferences, all within a downloadable application that is available for both iOS and Android devices.[21,22]

SAFE INTERSECTION CROSSING

Carnegie Mellon University (CMU) is developing a tool to connect pedestrians with disabilities to nearby connected traffic infrastructure, such as vehicles and traffic infrastructure, to improve the safety of intersection crossing. This project involves a dedicated short-range communication (DSRC)-based mobile app for pedestrians with disabilities that allows direct interaction with the intersection. Since most smartphones do not include a DSRC radio, the phone is coupled with a radio "sleeve" to provide connection to the signal infrastructure. The app would integrate with Surtrac adaptive traffic signal systems to enable safe and efficient intersection crossing.[108]

The project will offer pedestrians customization features within the app to directly communicate personalized crossing constraints to the intersection, influencing traffic control decisions to ensure safe crossing for the pedestrian. The intersection will communicate intersection geometries to the mobile app to facilitate navigation. In addition, the mobile app will provide the pedestrian's route information to the intersection. This will assist the intersection in anticipating pedestrian arrival, and the intersection can adjust timings to streamline crossing time. The communication between the mobile app and the intersection will also actively monitor pedestrian crossing progress, allowing the intersection to extend green time if necessary.

CONSIDERATIONS

The concepts covered by the Complete Streets design philosophy encourage mobility and access for all, with accessibility and diversity of modes identified as priorities. Specifically, wide sidewalks for pedestrian safety, separation of modes for safety, diversity to reduce congestion, and curb management to encourage curbside uses other than parking. Complete Streets can continue to improve, with collaboration between municipalities and outreach to inform the public of the benefits of reimagining roadway design. Separating travel modes within the public right-of-way and furthering human-centered roadway design, Complete Streets policies help reduce crashes and support multimodal mobility. The Complete Streets policy objectives are to make communities healthier, help the environment, and improve the utilization of the public right-of-way.

Effective curb management requires balancing existing demands for curb space while adjusting for evolving modes and loading/unloading needs. Dynamic signage, electronic payment systems, and updates to regulations to accommodate new mobility trends can further optimize curb use. The rapid growth of TNCs and micromobility devices should be accounted for within curb use.

The mapping of pedestrian paths to determine accessibility is important not just for the disability community, but important information for municipalities for determining maintenance needs. The mapping of pathways by pathMet, in coordination with pathVu Navigation, could encourage new modes of mobility for users of wheelchairs and the visually impaired communities.

The safe intersection crossing application could not only offer significant benefits to pedestrians with disabilities, expanding the project to the broader public could benefit all pedestrians. Traffic signal hardware could communicate with multiple pedestrians simultaneously and adjust timings to increase pedestrian throughput and reducing pedestrian congestion at intersection sidewalks. If the signal-side technology expanded to become available across most major cities, the DSRC radio antennas could be integrated into smartphone hardware, streamlining the in-hand design and further boosting the potential user base. If DSRC is not broadly implemented, but cellular vehicle-to-everything (C-V2X) became the standard transportation communication technology, it's possible that smartphone hardware could be designed to communicate with V2X without additional hardware, keeping smartphone costs down.

Barrier-specific Commentary: Accessible Streets

Mobility Barrier	Select Comments
Physical limitation or disability	• Providing safe spaces for various modes to operate encourages alternative forms of transport. • Wider sidewalks allow individuals with disabilities to navigate the streetscape more easily, without disruption. • Technologies like pathMet can be used to identify and address problems with pavement condition.
Cost	• Supporting a transportation environment where commuters can safely travel via various modes (such as mass transit or biking) and encouraging alternatives to single-occupancy vehicles may reduce users' commuting costs. • Technologies (like pathMet) that can efficiently identify infrastructure issues, can help prioritize maintenance funding.
Coverage	• Modifying roads and curbs (for instance, converting public street parking to bus stops), could help to increase transit ridership.
Safety/Security	• Separating modes from each other – having safe places for pedestrians, bicyclists, and other alternative modes – creates safer spaces for all road users.
Awareness	• Identifying the location of accessible and inaccessible paths and disseminating this information, can help users to make informed, efficient travel decisions. This information can also be valuable to infrastructure owner/operators, potentially expediting repairs.
Technical limitations	• Ownership of a connected device may enable some to benefit more from mobile services, such as dynamic curb management programs. Increased technology penetration can increase the number of people who can potentially benefit from and utilize these services.
Design/Upkeep	• Effective, intentional, user-oriented design can help to encourage utilization of various modes of transportation. • Data collected can be leveraged for strategic maintenance. • Building and maintaining accessible streets may require more time investment, but may experience less strenuous loading from users.

IN-HAND TECHNOLOGY

According to the Pew Research Center, as of 2019, 96% of Americans own a cell phone of some kind and 81% of Americans have smart phones. While it is important to remember that not everyone has access to hand-held technology or associated data plans, the percentage of Americans with smart phones has risen significantly over the past decade (with only 35% of Americans owning a smart phone back in 2011).[109] The increase of connected, personalized, transportable technology can be a valuable tool in improving one's ability to tailor trip planning, navigate effectively, communicate with surrounding networks, and travel more safely and independently.

EMERGING ASSISTIVE DEVICES

Assistive devices are "external devices that are designed, made, or adapted to assist a person to perform a particular task. Many people with disabilities depend on assistive devices to enable them to carry out daily activities and participate actively and productively in community life."[110] The development of new, intelligent, assistive devices and associated standards offer the potential to improve wayfinding and mobility for target users.

Standards pertaining to how information is displayed or communicated can help make travel applications more accessible. The SMART Wayfinding Standard, for example, aims to "develop a common route format for presenting travel instructions to individuals with cognitive disabilities to allow users of these wayfinding technologies to access and share routes that enable them to use public transit more independently."[21] This development is discussed in the Complete Trip section of this literature review. Features, such as visual or vibrating alerts, adjustable volume control, visual or tactile indicators for the keypad, mono audio, captioning, and more can also help to make mobile devices and services more accessible.[111] As new tools and connected features become available, it is important that these increasingly mainstream features be included.

With respect to emerging navigation tools: The City College of New York (CCNY), for example, is researching and developing navigation aids for the blind through both public and private grants. One of their partnerships, for instance, was with Google Tango, an augmented reality (AR) platform using computer vision to allow mobile devices to detect their position relative to the world around them without using external signals, such as GPS or cellular signals. Though Google ended support for Tango in favor of ARCore, partnerships leveraging AR technology offer potential to improve independent mobility for individuals with low vision. Another one of CCNY's projects was the Intelligent Situation Awareness and Navigation Aid (ISANA) system, a mobile, wearable, context-aware prototype system that can act as an aid to blind or low-vision individuals, guiding travel while indoors. The system uses spatial semantic information from building architectural models to form a map, and uses a depth sensor mounted on the device detects obstacles. Based on the data collected between the motion tracking, semantic map, and depth sensor, the system generates a safe path to the wearer's destination. There is a speech interface for user input, guidance, and alert cues in real time.[112]

The Smart Cane for Assistive Navigation (SCAN) project is a smart-cane hardware and integrate new algorithms into this previously developed ISANA system. One goal of the SCAN project is to mitigate the problems caused by the non-perfect user interface, tackle technical challenges in complex indoor environments, and expand the ISANA capabilities to provide blind users with independent travel in transportation terminals and outdoor pedestrian environments.[23,24]

CCNY intends for the SCAN project to develop into a next generation wearable wayfinding and navigation system. This system would include a smart-cane device with a rolling tip which detects human intent from the operator, allowing blind travelers to feel and follow turn-by-turn instructions more accurately than existing cane use, as well as provide proximity sensing for obstacle avoidance. The SCAN system would also include a smartphone running an app-based interface, providing semantic localization, path planning, and navigation in both indoor and outdoor environments. This software app can also be used by normal sighted persons to aid in navigating complex indoor environments such as transportation hubs, shopping malls, and airports.

Figure 19: An instructor tests the interaction between smart paint and a smart cane; Source: GovTech

In addition to the development of in-hand technologies to aid individuals with low vision, private enterprise is also involved with developing additional methods. Intelligent Material is collaborating with several universities and cities in developing a "smart paint," featuring specially-aligned light-converting oxides to passively communicate information to various technologies. This specialized paint could be installed along sidewalks and in crosswalks, and interact with a smart cane to provide guidance and wayfinding information to the pedestrian with low vision. In addition, this paint could be applied within roadways, providing AVs with precise location information and allowing GPS recalibration to correct drift.[113] Several partners, including the Ohio State School for the Blind and Columbus Smart Cities, are testing smart paint installations.[114]

VEHICLE-TO-PEDESTRIAN COMMUNICATIONS

In 2013, more than 5,500 pedestrians, bicyclists, and other nonvehicle roadway users were killed in motor vehicle collisions in the United States. This number has stayed consistent over recent years, despite the total number of fatalities in motor vehicle collisions falling over recent years. This suggests that, while the national auto fleet is getting safer, the safety of nonvehicle road users is not improving with them.[115]

The deployment of vehicle-to-pedestrian communications (V2P) could be one way to improve safety for nonvehicle road users. V2P would be a communications system between vehicles, traffic infrastructure, and pedestrians that would enable safety, mobility, and environmental notifications that are not currently possible. This vehicle-to-everything (V2X) technology is expected to reduce vehicle collisions by 80%.

USDOT is researching V2P systems that operate with either pedestrian detection to alert approaching vehicles at locations such as crosswalks; and handheld devices to provide information directly to pedestrians. An example of the handheld system is the Mobile Accessible Pedestrian Signal System, an app that can effectively press the pedestrian call button at crosswalks as the user approaches. This system could be very useful for individuals with low vision, or pedestrians in wheelchairs if the pedestrian button was placed in an inaccessible location. In addition to the automated pedestrian call feature, the system could alert drivers making a right turn on a red signal if a pedestrian is utilizing the crosswalk.

It should be noted that in-hand technology that connects to V2P systems often requires specialized antenna hardware that attaches to smartphones, creating an additional burden in size, complexity, and cost to pedestrians. However, if an industry standard for V2P communications is realized and experiences broad public deployment, this hardware could be added to future smartphone design, reducing complexity and cost to the end user.

Some vehicle-to-pedestrian communication examples, such as Carnegie Mellon University's Safe Intersection Crossing application, are discussed in the Accessible Streets section of this literature review.

SMART CITIES

A smart city is a municipality using connected devices to collect and disseminate data to manage available services. The data is collected from city-owned sensors, through data-sharing partnerships with private companies, citizens, or others. The data collected could be used for traveler information, traffic management, utilities, waste management, crime detection, parking inventory, and more.

As cities deploy these new technologies to inform citizens of available services, the accessibility of the provided services needs to be a priority. US law does not specify how municipalities design or implement digital services for individuals with disabilities, and many new systems are not designed with an eye towards accessibility. For example, many smart city kiosks, used to provide information and direction to users requesting information, provide input via a touchscreen interface. An individual with a physical disability may have difficulties operating a touchscreen interface, and an individual who is blind may have trouble accessing displayed information unless the device provides screen-reading or audio functionality.[116]

Similarly, cities that utilize apps to solicit and address feedback from citizens may inhibit older, low-vision, or low-income from sharing their opinions. Some groups of the citizenry, including older populations and low-income households, do not own smartphones. Prioritizing the use of smartphone apps, while convenient, can lead to stratification of the data collected. For interfaces to be accessible, awareness of the needs of the disability community is paramount.

CROWDSOURCING & ACCESSIBILITY

Crowdsourcing is the practice of collecting data and information from a large group of participants. This data and associated analysis can lower barriers for individuals with disabilities and others with unique needs. Volunteers with smartphones can provide audio directions, tag locations that may lack accessibility, and more. As the accuracy, quantity, and capacity of location devices grows, it will become easier to contribute to and benefit from the crowdsourced data.

Crowdsourcing can be used to identify public spaces, resources, and pathways that meet specific needs of accessible mobility. This information can be provided to publicly available mapping software and used to indicate location and routing to accessible options. As an example, Google Maps includes editing features that allow users to submit accessibility details about locations and businesses, which can then be seen by other users.[117] Another example is a project called Wheelmap, which uses crowdsourcing to improve granularity of its collected accessibility data, identifying differences between locations that are fully wheelchair accessible, partially accessible, and not accessible.[118]

Crowdsourcing can also assist in improving the quality and accuracy of wayfinding resources for individuals with visual impairments. These individuals often experience a problem often called “the last 50 feet,” used to describe the fact that, while GPS can direct people to a general area, its accuracy can leave gaps in wayfinding coverage as one reaches a destination. This limitation makes it difficult for those with vision impairments to “find specific locations like bus stops or building entrances,” which may limit their ability to get around independently. The Perkins School for the Blind is developing a program that intends to mitigate this “last 50 feet” problem using a crowdsourcing model.[119] With a grant from Google, the school is developing tools to enable volunteers to dictate directions that users with visual impairment can listen to when they are close to their destination, such as transit stops or municipal buildings.[120]

Crowdsourcing can help address accessibility needs that may be beyond the scope of accommodations traditionally covered by the Americans with Disabilities Act (ADA). As an example, The Missouri Disability Empowerment (MoDE), a nonprofit advocacy group, created RestroomMap.com, a crowdsourced mapping tool that intends to assist those in need of specific restroom facilities. MoDE’s mapping tool displays the location of verified public restrooms that match select criteria, such as whether the location features facilities that are unisex, family, or family with an adult-sized changing table. Restroom tags are added by the public through an online form on the website, and all submissions are verified by volunteers to ensure accuracy. Since the site launched in early August 2018, approximately 400 restrooms have been added to the crowdsourced map. Through crowdsourcing, not only will existing accessible resources be easier to locate for those who need them, MoDE hopes that the tool will help to “point out what it calls ‘restroom desserts’ to businesses and local governments.”[121]

Figure 20: A screenshot of MoDE's RestroomMap.com, showing a family restroom with universal changing table at the Toronto Zoo; Source: RestroomMap.com

Current crowdsourcing initiatives often draw upon active participation from contributors, requiring actions that can be time-consuming. This process of providing, aggregating, and analyzing quality information is likely to advance with automation and technology. With a large contingent of the public carrying one or more smart device, such as smartphones, fitness trackers, and the like, it is increasingly easy to collect large quantities of detailed data. AI is incorporated into more products, real-time language translation, captioning, and image recognition can be incorporated into existing mobile devices.[122] As image recognition improves and machine learning expands into consumer spaces, confirming the accessibility of sidewalks, buildings, and intersections could become as easy as taking a picture, or leaving an application open while walking. An AI could analyze the pedestrian density of public spaces, combined with satellite images and building floor plan overlays as additional inputs, to identify areas of limited accessibility.

ACCESSIBILITY AND HUMAN-MACHINE INTERFACE

The human-machine interface (HMI) of a system can significantly impact its usability and accessibility. The early devices and designs to reach the market may have exclusivity advantages, but if the interface is difficult to understand, it will not likely lead to a successful deployment. As an example, early versions of small multi-purpose communication devices, or smartphones, came with physical keyboards, small monochromatic screens, and required stylus input. Their usefulness was understood, but they were cumbersome to use. The launch of the iPhone's design, featuring a large touchscreen with only four physical buttons, was much more intuitive. Today, most smartphones sold mimic the basic design of few physical buttons and large touchscreen of the original iPhone.[123,124]

As identified in the Automation section of this literature review, the broad adoption of a universal design approach – designing in-hand technology to be usable by all people, to the greatest extent possible – would enable innovations to benefit a more varied user base. Most in-hand technology is being driven by the tech industry, as well as the increasing market penetration of smartphones. The tech industry has been more accommodating for universal design, mainly because their platforms are designed for software updates to improve functionality, and adding accessibility is relatively simple.[36]

CONSIDERATIONS

There are challenges to digital mapping and the crowdsourcing of accessibility information. While digital maps and crowdsourced information platforms can provide valuable tools, GPS accuracy available to the general public can be as poor as 30 feet.[120] In addition, crowdsourced information is only as good as a data behind it, with the accuracy and granularity of output information generally dependent on the quality, quantity, and representative breadth of the data that is input. Associated privacy and information security can also pose challenges. Passive data collection (for example, an app that runs in the background, sharing information) can generate concerns about exposing too much personal information;[125] self-reported data, while elective, can be inaccurate. As an example, self-reported data from a volunteer may identify a bathroom on a floor above ground level as handicap-accessible because it includes a large stall labeled as for individuals with disabilities; however, if the building lacks an elevator or ramp from the ground floor to the labeled location, then the bathroom is not accessible. Taking issues like these into consideration, and adjusting expectations accordingly, can help to strengthen future crowdsourcing tools.

Another significant consideration of in-hand technology is likely the barrier to entry, namely the acquisition of the in-hand technology itself. While the hardware capabilities and iterative nature of the software of modern smartphones creates an excellent platform to design from, the price of the hardware can be prohibitively expensive. Even entry-level models cost hundreds of dollars, plus the cost of connectivity is an ongoing expense that low-income users may not be able to afford. While there are subsidies available to some low-income residents, there can be gaps between provided subsidy, total cost, and a user's available budget.

In addition to cost, there can be a learning curve to using smartphones and other new technologies that may present a barrier to some users. Individuals that could otherwise benefit from available services (such as screen readers, ride-booking platforms, speech-to-text transcription, etc.), may not use them due to apprehension or inexperience, for instance. To address these concerns, educational outreach efforts, such as seminars with hands-on training held at community centers, could be of value. Much like how Voyage is testing the AVs within senior communities, thereby introducing the new technology to a tech-adverse population, smartphone makers or assistive app developers could introduce potential users through hands-on experience at public workshops. Moving forward, it may be beneficial for local government and other invested stakeholders to be involved in promoting public awareness of new technologies and services, as well as supporting related policies and standards for intuitive, consistent design to promote accessibility.

Barrier-specific Commentary: In-Hand Technology

Mobility Barrier	Select Comments
Physical limitation or disability	• In-hand devices can assist users of all abilities with wayfinding and navigation. • Accessible interfaces are critical for individuals with limitations associated with low vision, low hearing, dexterity, etc. • Universal design for technology interfaces is critical to accessibility. • Mobility related apps and services are increasingly offering integrated features that can help with personalized trip planning. • Crowdsourcing services are becoming more available through more in-hand devices and can help all travelers meet their specific needs.
Cost	• In-hand technology often requires a wireless data connection. Costs associated with these data plans can be a barrier for users.
Coverage	• Specialized wayfinding and navigation tools can help fill gaps in transportation coverage. • In-hand technology often requires wireless signals, which can be lacking or lost in buildings or elevators, and may be sparse or non-existent in rural areas. This can therefore present a barrier.
Safety/Security	• V2X communications have the potential to reduce vehicle collisions and save lives. • V2P communications can potentially provide safety improvements (such as approaching vehicle warnings) and quality of life improvements (such as walk time extensions at crosswalks) for all pedestrians.
Awareness	• Since crowdsourced data is collected from individual submissions, it is important that there be awareness of the platform and sufficient participation for resulting information to be accurate and useful.
Technical limitations	• Though some individuals may not have access to (for instance) a smart phone, publicly available kiosks can offer public interfaces.
Design/Upkeep	• Any platform aggregating information is only as good as the collected data. Therefore, considering what data is represented, and what data may be lacking, is important. • Increased deployment of V2X hardware can offer better connected coverage and increase the likelihood that users will utilize associated connected features and services.

CONCLUSION

An individual's ability to move independently is critical to a healthy, productive lifestyle. As new services and technologies are developed there may be opportunities to both leverage these innovations and reconsider current transportation norms in order to help improve mobility for all. Some of the key findings and/or takeaways from this literature include:

- For a trip to be accessible, every piece of it – from start to finish – must be accessible. Identifying gaps in service, using the Complete Trip philosophy, can help identify and address barriers.
- Evolving technologies and services, including AVs, MOD, and mobile applications, offer the potential to significantly transform the transportation ecosystem and reduce existing mobility barriers.
- The continued growth of communication infrastructure and smartphone penetration has increased connectivity. V2P communications can potentially help to improve road safety and integrated transportation applications may help travelers to better understand and utilize available mobility options. Connectivity, paired with automation, can also potentially improve the operation of vehicles and help to reduce commute times, hopefully making traveling safer and more efficient.
- With AV design still in its initial stages, automobile manufacturers should seek feedback and involvement (for examples, via surveys, pilot testing, etc.) from the full range of potential users. AVs present the possibility of significantly improving independent mobility for members of the disabilities community, among others. For AVs to be accessible to individuals with disabilities, however, accessible design is critical. Dynamic vehicles including accessibility features that accommodate wheelchairs and other mobility aids would help to make this new technology more widely utilizable.
- Bias in AI training datasets can lead to biases built into identification and decision algorithms. Identifying potential biases, and being vigilant about addressing them when discovered, is important.
- MOD can help to in fill gaps in transit services, by (for instance) providing first/last mile service to and from transit centers. MOD can also help to more efficiently and cost-effectively provide service to paratransit customers – potentially benefiting both riders and transit agencies.
- Implementing a Complete Streets philosophy in urban roadway design can improve user's transportation options, health, and safety.
- Updates to curb management policies and priorities can reduce congestion while improving accessibility for all users. Emerging technologies, including dynamic signing, smart parking, and CV communications may help optimize curb use.
- Leveraging technology to identify accessible and inaccessible routes, sidewalks, and trails can help users with disabilities to safely and efficiently reach their destinations, while helping municipalities prioritize and triage pathway maintenance.
- While the capabilities available in modern smartphones present opportunities to improve accessible services, such as wayfinding and crowdsourcing solutions, it is important to consider barriers that may remain for various vulnerable populations, such as those who are low-income.

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