Transport Accessibility of Persons with Reduced Mobility: the Challenge of Autonomous Vehicles and AccessibleEU

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Abstract

The paper presents in the first instance the changing socio-demographics of persons with reduced mobility (PRMs) and persons with disabilities (PWDs). The European legal framework scoping on PRMs and PWDs together with a recent AccessibleEU initiative for its implementation is briefly introduced. The legal framework focuses on public transport accessibility. Categories of PWDs and PRMs, which are relevant to the transport mobility behaviour, are defined. A description of automated vehicles (AVs) is presented. The current travel behavior of PRMs, their future use of AVs and issues of universal design and AV accessibility are examined. The emphasis, being policy-orientated, is on the appraisal of pros and cons of AVs' use by PRMs. Finally, research gaps related to the future use of AVs by PRMs are revealed.

Περίληψη

Περιγράφονται αρχικά τα μεταβαλλόμενα κοινωνιο-δημογραφικά χαρακτηριστικά των ΑμεΑ κα των Ατόμων με Περιορισμένη Κινητικότητα (ΑΠΚ). Ακολουθεί μια σύντομη εισαγωγή στο Ευρωπαϊκό νομικό πλαίσιο σχετικά με τα ΑμεΑ και ΑΠΚ καθώς και στη πρόσφατη πρωτοβουλία ΠροσβάσιμηΕΕ της Ευρωπαϊκής Κοινότητας για την υλοποίηση του πλαισίου. Το νομικό πλαίσιο εστιάζει στη προσβασιμότητα των Δημοσίων Συγκοινωνιών. Ορίζεται μια κατάλληλη κατηγοριοποίηση των ΑμεΑ και ΑΠΚ σε σχέση με τη ταξιδιωτική συμπεριφορά τους. Περιγράφονται στοιχεία των Αυτόνομων Οχημάτων (ΑΟ). Εξετάζεται η υφιστάμενη ταξιδιωτική συμπεριφορά των ΑμεΑ, η μελλοντική χρήση των ΑΟ από τα ΑμεΑ, όπως και θέματα καθολικού σχεδιασμού και προσβασιμότητας των ΑΟ. Δίδεται έμφαση στα πλεονεκτήματα και μειονεκτήματα της χρήσης ΑΟ από ΑμεΑ αποσκοπώντας στη διαμόρφωση πολιτικών και δράσεων. Τέλος, επισημαίνονται ελλείψεις της έρευνας σχετικά με τη μελλοντική χρήση των ΑΟ από ΑμεΑ.

Keywords: *Person with Reduced Mobility, Person with Disabilities, mobility barriers, accessibility, autonomous vehicle, transport infrastructure, community of practice, public awareness raising*

Λέξεις-κλειδιά: *Άτομο Περιορισμένης Κινητικότητας, Άτομο με Αναπηρίες, εμπόδια κινητικότητας, προσβασιμότητα, αυτόνομο όχημα, υποδομή μεταφορών, κοινότητα σκοπού και πρακτικών δράσεων, προώθηση δημόσιας ευαισθητοποίησης*

1. Introduction

Mobility is a condition to participate in social life. Being able to move is a prerequisite to perform outdoor activities like work, medical appointments, leisure or tourism. Accessibility barriers lead to less social interactions and less participation into the labour market. A lack of accessible transportation may be an obstacle for life opportunities. This is an important reason that an equitable access to transportation for all citizens is requested. The thread and the practical application of the paper is: contributing to a potential increase of the independence of Persons with Reduced Mobility (PRMs), i.e. Persons with Disabilities (PwDs) and older persons through the use of Autonomous Vehicles (AVs). PRM is used as an umbrella term in this paper. The mobility of PRMs is conditioned not only by their impairment or limitation but also by the environment. An appropriate transport service provision and infrastructure would moderate the relationship between having a disability and lower rates of travel activity.

A main objective of the paper is the appraisal of pros and cons of AVs' use by PRMs. The methodology followed is an extensive audit of the relevant literature and an identification of the most prevalent research gaps. A novel aspect of the paper is a policy-oriented meta-analysis of pertaining reviews. The focus of the paper is on land transportation.

The paper is structured in 7 sections. Section 2 presents the changing socio-demographics of PRMs. The European legal framework scoping on persons with reduced mobility andpersons with disabilities together with a recent AccessibleEU initiative for its implementation is presented in Section 3. An emphasis is posed on public transport accessibility. Section 4 refers to categories of persons with disabilities and PRMs, which is relevant to the research topic. The introduction and description of automated vehicles follows in the next section. The current travel behavior of PRMs, their future use of AVs and issues of universal design and AV accessibility are examined in-depth in section 6. The last section reveals research gaps related to the future use of AVs by PRMs.

2. Changing socio-demographics

The prevalence and incidence of disability change over time and geographical area. The Council of EU (2022) reports that 24% of the European adults are persons with disabilities (Greece: 23,1%). Concerning age, 48,5% of people with disabilities in the EU are aged 65y.+. To compare with, the same share in the general EU population by 2021 accounts to 20,8%. There is a close association between (older) age and disability. With the EU population getting older, the number of people with disability in EU is set to increase. In general older old persons (80y.+, even without disability in earlier life stages) tend to acquire health-related impairments and conditions and may then be considered as PRMs.

Note that income distribution is more inequitable for disabled people, whereby low income groups have a greater prevalence of disability. People with disabilities are 50% more likely to be at risk of poverty and social exclusion (Council of EU, 2022)

3. EU legal framework and AccessibleEU

The European Accessibility Act (EAA, Directive EU 2019/882) is the European counterpart of the Americans with Disabilities Act (ADA), but more reduced in scope. EAA promotes accessible products and services to the benefit of Persons with disabilities (PWDs) and elderly people, thus seeking a more inclusive society. Universally accessible mobile apps, smartphones, websites or automated ticketing machines are examples considered in the EAA. However, few accessibility requirements are foreseen for wide sectors of road transport and built environment. Member states had to pass the necessary implementation laws by June 2022, and ensure the implementation of the accessibility measures contained in the EAA by June 2025. Very few EU countries have already transposed EAA into their national legislation by June 2022.

Concerning long-distance, inter-urban public transport, there exist Regulations on Rail (No 1371/2007) and Bus Passenger Rights (No 181/2011) defining non-discriminatory access rules; Technical Standards and requirements for facilitating access to PRMs are set out for rail (Regulation No 1300/2014) and buses (Bus Directive 2001/85 and UNECE Regulation 107/2014). Regulations are binding for the public procurement of vehicles, thus, for the vehicle manufacturers too. European standards for accessibility in railway systems are EN 16584-1:2017 (Contrast), EN 16584-2:2017 (Information), EN 16584-3:2017 (Optical and friction characteristics) and EN 16587:2017 (Obstacle-free routes). Enforcement of regulations is a matter of national government.

The AccessibleEU resource centre is an initiative launched by December 2022 to promote the practical implementation of accessibility-related policies and legislation across sectors of transport, built environment, tourism, information and communication technologiesin all EU Member States. AccessibleEU actively supports standardization related to above sectors across EU, engaging PRMs in this respect (www.accessibleeucentre.eu, 2023).In the long-term is aimed a barrier-free Europe. Leader of the project is the Spanish Fundacion ONCE, co-working with 4 other partners, among them ENAT.

4. PRM categories in the transportation sector

A ‘person with reduced mobility’ means any person whose mobility when using transport is reduced as a result of any physical disability (sensory or locomotory, permanent or temporary), intellectual disability or impairment, or any other cause of disability, or as a result of age, and whose situation needs appropriate attention and adaptation to his particular needs of the services made available to all passengers”[1]

A suitable typology of disabilities would distinguish among physical, sensory (visual, hearing), cognitive and other impairments:

[1]REGULATION (EU) No 181/2011 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 February 2011concerning the rights of passengers in bus and coach transport and amending Regulation (EC) No 2006/2004

- *Physical disabilities* refer to walking limitations (frequent use of mobility aids such as walking stick, rollator, crutches) and wheelchair-users. Older persons may typically have walking difficulties.
- *Visual impairments* refer to persons with visual impairments and blind persons (use of white cane, guide dog or escort person). Visually impaired are dependent on audible communication and tactile means.
- *Hearing impairments* refer to persons with hearing impairments, including Deaf persons. Persons with a hearing impairment are dependent on visual communication.
- *Cognitive deficits* leading to distraction and communication problems. Older age is associated with cognitive deficits and slower reaction or physical co-ordination.
- *Other disabilities,* like developmental ones (e.g. autism) leading to serious communication problems. Hidden disabilities include but are not restricted to mental ones.

Every kind of disability has differing functional needs and experiences differing barriers in the everyday life.

5. Automated vehicles

Vehicle automation has different levels from ‚no driving automation (Level 0)' to ‚full driving automation (Level 5)' (SAE 2018). This paper focus on driverless Level 5 which is expected to be reached after 2030. Automated Vehicles (AVs) will be by then essentially Electric Vehicles (EVs) too. Increased transport automation may ensure safer traffic, road space efficiency or more inclusive mobility (i.a. adults without driver license, persons < 17y. old, PRMs). They may also lead to recurring congestion or urban sprawl. Strictly speaking, autonomous vehicles are automated vehicles using sensors only. Many automated vehicles are connected to other vehicles (V2V) and infrastructure (V2X). In the literature, however, the labels 'automated vehicle' and 'autonomous vehicle' are used many times interchangeably.

Gaitanidou et al. (2022) discuss the deployment of AVs in Greece, where road safety has been traditionally a critical issue; insights are gained through a survey of experts, local authorities and transport operators. Small-scale pilots have taken place already in Greece, one of them involving an automated shuttle bus in Trikala by 2015. Deloukas et al. (2021) have developed within ongoing H2020 FRONTIER project an AV-related governance framework for Attica, involving public (OASA, ATTIKO METRO, OSE) and private actors (ATTIKI ODOS, HELLENIC TRAIN). The suggested AV-inclusive regulatory scheme, being both state- and market-driven, is deployable in the case study of the corridor D.Plakentias to the Athens International Airport, where AVs may be used as a First Mile/Last Mile (FM/LM) access mode to the urban rail system.

6. Transport mobility behavior of PRMs

6.1 Mobility dimensions

The mobility behaviour of PRMs differs from the mobility behaviour of people without disabilities in terms of *trip frequency by purpose, mode choice, Value of Time (VoT), travel distance or route choice*. The focus here is on persons with walking difficulties, sensory impairments and cognitive deficits. Park et al. (2023) show evidence that the above-defined PRMs make fewer trips (with the exception of medical trips) compared to those without disabilities. This is partly explained by lower employment rate, older age and, of course, still existing mobility barriers. Disability severity decreases even more the trip frequency. Note that immobility and isolation at home may lead to despair and depression.

Comparing with the general population, disability is associated with increased use of public transport (PT) or riding with others in personal vehicles and with a decreasing driving, walking and biking modal share. Walking is hindered by inaccessible and unsafe pedestrian space (e.g.broken tiles, illegally parked cars). Although many PT vehicles are accessible for PRMs, a significant number of stops and stations are inaccessible. Breakdowns of lifts and escalators often hinder the use of heavy urban rail. Most non-driving PRMs must rely on family members or friends for rides. Ride-sharing with others increases with severity of disability. Limited modal options or even mode captivity are still a reality today for most PRMs.

Stated Preference (SP) experiments with PRMs revealed a value of access/egress time to/from PT 4 times higher than that of the in-vehicle time (Marquez et al. 2022). The same ratio is only two times higher in the general population, thus PT access is less of a burden. Similarly, PRMs would prefer more door-to-door service (i.e. without modal transfer) than the general population.

In terms of travel distance, disability is associated with shorter distances. Disability severity decreases the frequency of short-range trips and increases the respective one for shortest trips. Many PRMs are even restricted to their homes without travel activities at all.

PRMs that walk or wheel may consider factors other than distance, such as the width of sidewalk segments and slope when making route choice decisions, while seeking obstacle-free, accessible routes.

Changes of PRMs' travel patterns in the future are an important research topic (Dicianno 2021).

6.2 Automated vehicles and PRMs

Most research on transport disadvantages among PRMs has focused onto the accessibility of using *PT*. Related issues pertain mostly to physical accessibility (e.g. long distances to stops, no level boarding), malfunctioning equipment (e.g. lifts to metro platforms), lack of audible announcements, cancelled services or digital accessibility (e.g. ill-designed Human-Machine Interfaces /HMI/ of websites and mobile apps). The disadvantage is accentuated in semiurban and rural areas underserved by PT. A widely-used good practice is, however, the offer of concessionary fares (Greece: free for PWDs, 50% discount for seniors).

An alternative transportation option refers to *on-demand paratransit* (point-to-point service), provided or subsidized by the community to assist PRMs. However, prevailing challenges refer to the location, service time, waiting time and delay, advanced booking (no spontaneous use) and costs to PRMs and to the community.

More flexible are *private modified vehicles* (PMVs) with hand control, pedal extension, steering knob etc. Available are also adapted vehicles for wheelchair users. PMVs are typically adopted by persons with problems of their feet or legs, difficulty of gripping or holding etc. However, the cost of adapting a vehicle may exceed the initial cost of the vehicle (Darcy and Burke, 2018).

Autonomous vehicles present a future opportunity to improve mobility of PRMs, especially drivers facing barriers even with PMVs as well as non-drivers. AVs could offer PRMs door-to-door service (even in remote areas) and increased flexibility and independence. PRMs do not need to waste time for parking search because parking spot and travel destination are dissociated: empty AV rides could reach the spot after the drop-off and return back for the pick-up of the rider.The essentially electric AVs could recharge themselves by moving without riders to energy stations with inductive technology, i.e. while not in use (similarly to current automated parking within garages). The mobility of non-driving PRMs is in many cases (e.g. blind persons) dependent on other persons; it is expected that AVs would be a viable option to support a more independent mobility (Hwang, Kim, 2022). It should be noted that driving PRMs exhibit higher trip rates than non-driving PRMs. Thus, in terms of transportation justice, AVs could have a higher equity impact on non-driving PRMs (Petrovic et al. 2022). Finally, note that older drivers may be more reluctant to give up traditional driving than younger ones.

Potential issues with the use of AVs by PRMs pertain to feeling of no control and perceived safety, lack of trust for a new disruptive technology, affordability, physical and digital accessibility and other. *Acceptance* of AV use may be increased through information, education and training by specialized instructors and professionals. Collaborative schemes of initiatives like AccessibleEU, AV manufacturers and municipalities could work in this direction. The *affordability* of costly AVs for PRMs is increased through shared AVs (Goralzik et al. 2022). Insurance costs will decrease in any case due to fewer traffic accidents; the liability of AV owners will fall while increasing the liability of AV manufacturers. Shared AVs will decrease the cost of owning or using, making AV travel more affordable. A regulatory scheme incentivizing Mobility-as-a-Service (MaaS) solutions and AV ridesharing would be more sustainable and equitable than promoting privately owned AVs. Ridesharing is also prone to be a supplement of a high-capacity PT line haul, e.g. as a FM/LM mode feeding train hubs (Deloukas et al. 2020).

6.3 Universal design and accessibility of AVs
The accessibility of AVs and related infrastructure is further discussed with reference to facilitating the mobility of PRMs through the universal design of transport-related infrastructure and service provision.

The Universal Design (UD) approach towards promoting social inclusion was developed in the 1990s by architects in the domain of built environment. Later it has been taken up in the domains of ICT and transport. Stepless access to passenger carriages is one highly valued example of the application of universal design, enabling ease of entry and exit by all persons, including those with disabilities. Applying the UD principles to the designs of the whole trip chain and integrated multi-modality avoids fragmentation and mobility gaps. The term 'accessibility' in the field of transport is more restrictive and refers specifically to solutions applicable to the access requirements of PRMs. Certain design products, such as PMVs, refer to accessibility of PRMs rather than of the general public. For example, the largest British digital marketplace for conventional and electric cars asks for barrier-free charging stations with lower charge points and payment machines, permitting their use by drivers who may use a wheelchair or have walking difficulties or other mobility restrictions. (Autotrader.co.uk 2023).

Within the whole *chain of accessibility*, special attention has to be given to the vehicle design pertaining to getting into and getting out of AVs without assistance. The *physical accessibility* for manual wheelchair users requires either level boarding or a ramp with a max. 1:6 slope. The underfloor electric battery is a constraint for wheelchair entry as it typically raises the floor height of the vehicle due to its thickness. There is a technical solution with a thin retractable ramp underfloor and above the battery. Alternative transfer systems make it possible for wheelchair users to occupy an AV seat without a ramp: a swivel seat post enables the car seat to rotate to help the driver get in and out. Storage capacity for assistive aids has to be foreseen. Minimum door height and width have to be set by technical standards based on ergonomic factors. The development of accessibility standards and functional requirements for upcoming innovations (e.g. AVs) are a concern of the AccessibleEU initiative.

Equally important is the *digital accessibility* of transport modes. Antoniou et al. (2020) report the development of a universally accessible travel companion (mobile app) for chained trips within H2020 My-TRAC project; the app exchanges data and information about traffic disruptions with an operators' platform too. AVs should provide on-board auditory and visual communication to PRMs, in order to reduce their cognitive load and their possible anxiety. People with cognitive impairments need easy-to-understand HMIs (Ferati et al. 2018).

Legislation for a universally accessible fleet share system for ride-hailing operators and car rentals is required. The involvement of PRMs in developing accessible design solutions and laws governing the operation of AVs is essential. Moreover, field operation tests of AVs are required to involve PRMs in co-design and assess their needs and acceptance. This is an area of vehicle design that is ripe for innovation, offering potential benefits for all users, both disabled and non-disabled, in terms of safety, comfort and convenience. The UD approach may also contribute to cost-savings for manufacturers, as it reduces the need for subsequent adaptations.

7. Research gaps

Several open questions remain, referring to the acceptance of AVs by PWDs and older persons. Are they going to feel comfortable in using a vehicle without a driver? Are shared AVs adequate for PRMs? Is the digital divide within PRMs critical pertaining to the use of AVs?

Further under-researched topics attracting attention are:

- Training content for instructors of varying kinds of PRMs using AVs and topics of education for PRMs
- Need of escort assistants at the commissioning phase of AV use for building trust
- Connectedness of PRMs by type when planning, booking, and paying for travel with shared AVs
- HMIs for adapted apps, travel companions and smartphones with text-to-speech capability
- Assistive in-vehicle technologies for enhanced ambient control within AVs
- Privacy concerns for collected PRMs' data using AVs
- KPI development for AV use by PRMs (e.g. market size by type)

8. Conclusions

AVs have the potential to reduce mobility barriers for persons with different kinds of disabilities. The paper highlights the need for improving vehicles and infrastructure to serve the access of PRMs and provide recommendations for the design of accessible AVs. It is crucial to engage disabled and senior persons to establish their perceived constraints, needs and priorities pertaining to automated vehicles. Focus groups consisting of accessibility experts and persons with a range of different disabilities and ages could be consulted to get relevant information through in-depth discussions. The meta-analysis of literature pertaining to PRMs and AVs revealed, inter alia, important research gaps to be investigated in the future. Communities of practice are essential for public awareness raising towards PRMs as well as for training and capacity building of PRMs pertaining to the use of AVs. Facilitation of such communities as well as awareness-raising are a central concern of the AccessibleEU initiative. The latter initiative will broach the issue of the AV use by PRMs as well as pertinent EU legislation gaps, both in related workshops.

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