The Challenges of Producing and Integrating Accessibility Data as Stumbling Blocks for Seamless Travel Chains in Public Transportation and MaaS for All

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***Abstract*—This extended article presents the challenges that people with mobility and functional disabilities face in seamless travel chains of public transport and in Mobility as Service (MaaS) conceptualized solutions. Building upon our previous research presented at The Ninth International Conference on Universal Accessibility in the Internet of Things and Smart Environments SMART ACCESSIBILITY 2024, we explore how these challenges act as stumbling blocks in achieving truly inclusive mobility solutions. The study emphasizes that while transport accessibility for all is considered essential, passengers with temporary or permanent disabilities continue to face significant barriers. We investigate the complexities of creating both physically accessible environments and digitally accessible information systems, highlighting the increased difficulty when aiming to integrate various modes of transport into customized, seamless travel chains via MaaS platforms. The research conducted in the city of Riihimäki in Southern Finland and its surrounding areas maps the key accessibility information needs of people with various mobility and functional disabilities. We compare these needs against the accessibility information provided by official travel databases, including National Access Points (NAP). The study examines common standards for data sharing and the challenges operators face in data production and integration. The findings reveal that although essential accessibility information can be found in databases, it often remains inaccessible or is not available in MaaS conceptualized route guides. We identify multiple reasons for this data accessibility gap and propose areas for improvement in the current system. Furthermore, this extended version explores the integration of accessibility data into MaaS platforms, discussing both the challenges and opportunities this presents for creating truly seamless and inclusive travel experiences. We also consider the role of emerging technologies and universal design principles in overcoming these obstacles. By providing a comprehensive analysis of the challenges in accessibility data production and integration, this research offers valuable insights for policymakers, transport operators, and technology developers. The goal is to foster the development of more inclusive public transport systems and seamless travel chains, ultimately improving the travel experience for all users, regardless of their skills.**

Keywords-accessibility; barrier-free transportation; public transportation; travel chain; public transportation for all; digital accessibility; MaaS.

I. INTRODUCTION

This article is an extended version of the conference paper titled "Challenge of Producing Accessibility Data for Public Transport and Travel Chains" [1], which was presented at The Ninth International Conference on Universal Accessibility on the Internet of Things and Smart Environments (SMART ACCESSIBILITY 2024) in May 2024.

Transport accessibility for all is considered an essential right for a more equitable and fair society [2]. Accessibility refers to the physical environment, e.g., buildings, roads, stops, intersections, parks and other places, services, means of transport, etc. An accessible environment is a space that entitles everyone to free and safe movement, activity, and access, regardless of age, gender, or ability to function. It is about the extent to which the diversity of people is considered in the planning, implementation, and maintenance of the built environment. An environment, building, bus stop or train stop, or means of transport is barrier-free when it is functional, safe, and pleasant for users, and when all facilities are easy to access. In a barrier-free environment, the spaces and their functionality should be as easy to use and logical as possible. Barrier-free environments together with accessible services, usable tools, and comprehensible information realize equal inclusion. A universal design perspective intends to ensure the design and composition of an environment are achieved in such a way that it can be accessed, understood, and used to the greatest extent regardless of age, size, or ability. When spaces are designed to accommodate diverse needs from the outset, it benefits everyone—whether they have a disability or not.

According to the United Nations [3], sustainable transport aims to promote general accessibility, better safety, reduced environmental impact, flexibility, and greater efficiency. Sustainable transport is also expected to have effects on eradicating poverty, increasing equality, and combating climate change. In cases when the infrastructure, systems, and services are missing or are inadequate, the benefits of transport cannot be accessed. For example, remote rural areas are especially disadvantaged, as they often have poor links to regional and national transport networks. In some cases, the transport infrastructure and systems do exist, but they still fail to provide safe and convenient access for older persons and Persons with Disabilities (PwDs).

The European Union's Sustainable and Smart Mobility Strategy (2020) [4] aims to create a sustainable, inclusive, and resilient transport system that benefits everyone while addressing environmental challenges and embracing technological advancements. It emphasizes a smart, competitive, safe, accessible, and affordable transport network. According to the strategy, the principle of "No-one is left behind" underscores the commitment to create a transport system that serves everyone, promotes equity, and enhances the quality of life for all individuals across the European Union.

The Intelligent Transport Systems (ITS) Directive 2010/40/EU [5] and its Delegated Regulations require that each European Member State must establish a National Access Point (NAP) for mobility data. It aims to encourage the development of innovative transport technologies to create the ITS. It is part of a broader initiative to enhance connected mobility experiences in Europe. It serves as an open national gateway where mobility service providers must submit information about their digitally accessible essential data interfaces. NAP is not a service for end-users or passengers; rather, it is intended for mobility service providers and developers.

In Finland, the Act on Transport Services (643/2017) [6] obliges all transport operators to share information about their own services for the use of other operators in the sector. Data is shared through interfaces. Such interfaces are used to transmit information between two systems. Information on open interfaces is exported and compiled in the Finnish Transport Agency's NAP service catalogue [7]. The provider of mobility services for passenger transport must ensure that essential and up-to-date information regarding the mobility service is also available in a machine-readable format. Opened data is used for making route guides and traffic services, for example. The relevant information varies by service type. For example, there are two obligations to share interfaces concerning the municipal sector. The obligation to provide essential information applies to all providers of passenger transport mobility services, regardless of the mode of transport. This information concerns aspects such as, the route, stops, schedule and price information, as well as information about the availability and accessibility of the service. Another only those entities that have a ticket and payment system.

An estimated 87 million Europeans currently have some kind of permanent disability or temporary obstacles to movement or functioning [8][9]. In Finland, the number of people with various disabilities is estimated to be slightly less than 19% [10]. Whether it is a question of permanent or temporary obstacles to movement and functioning, obstructed infrastructure, inadequately guided routes, and insufficient digital travel information make traveling difficult. Public transport use and barriers to this use may be experienced differently by people with various types of disability, e.g., physical, sensory, or cognitive. To understand the various functional needs, these can be roughly categorized as follows: (1) *physical or motor disabilities* cause muscle weakness, balance difficulties or mobility limitation in physical movements, which in turn result difficulties walk, climbing the stairs, opening heavy doors; (2) *visual impairment* can vary from colour blindness, low vision to complete loss of sight in one eye or both, which causes difficulties navigating, visualizing spaces and seeing directional signs and other visual information; (3) *auditory disability* or hearing impairments can vary from low to complete hearing loss in one ear or both, resulting in difficulty hearing spoken language and auditory information; (4) *cognitive or learning difficulties*, affect understanding and memorization of instructions and texts; (5) a*ging*, can cause varying degrees of weakness in movement, sensory and cognitive functions; and (6) *temporary difficulties in movement, sensory or cognitive functions* caused by accidents, medicines or diseases, may limit movement in traffic [11][12]. Passengers with temporary or permanent disability of movement or function face difficulties using public transport services. Taking these aspects into account to build a physically accessible environment and to produce digitally accessible information from the former have proven to be demanding.

The challenge becomes even more demanding when the goal is to make the entire travel chain physically barrier-free and to combine different forms of movement into customized, seamless travel chains, with a digital delivery system via a single connecting service—Mobility as Service (MaaS) [13]. The characteristics of MaaS include the integration of multiple transport modes, various payment options, and the use of various technologies enabling the use of a single interface and platform while catering for personalization and customization to offer user-centric mobility services [14]. The origins of the MaaS can be found in ITS. MaaS is intertwined with the development of a sustainable transport system as a whole [15].

Currently, the literature on the barriers found in the built environment, on public transport and travel chains can be found relatively well [13][16]. On the other hand, there is very little literature about the type of information available on the environment and the public transport and travel chain and how this information is made available or used to serve the needs of PwDs. In addition, no literature is available on how the accessibility perspective of travel chains has been implemented in practice as part of MaaS services, e.g., in route guides. The final report of the Ministry of Transport and Communications in Finland (2022) [17] finds that at the national level, accessibility has not been considered much in Finland's first MaaS service pilots, and the measures to promote the accessibility of MaaS services have not been sufficient. To respond to this gap in the literature, this study aims to examine what kind of essential accessibility information is offered and how it corresponds to the critical essential accessibility information needs experienced by PwD in relation to the travel chain.

The content of the article is structured as follows. In Section II A, we examine what is meant by the travel chain and how the different stages appear to the passenger, as well as what is meant by the officially defined essential accessibility information of the travel chain. Section II B reviews MaaS services possibilities and challenges for implementation, legal, and user behaviour point of view. Section II C examines the accessibility of the travel chain in the light of previous literature. Section III describes the methodology used, the research area, the research object, the research participants, and the data collection process. In the results of Section IV, A, the critical accessibility information of the travel chain identified by PwDs during the planning phase of the trip and during a trip is discussed. Section IV B examines essential accessibility information identified from data sources and compares it with accessibility information defined as critical by PwD. Section V considers the development aspects of perceived and official essential accessibility information based on the results, and Section VI concludes the results regarding how the results can be used in the development of accessibility information for public transport travel chains.

II. Travel Chain and Barriers

A. Accessible Travel Chain and Essential Accessibility Information

When designing and planning public transport, travel chains, and built environments, it is critical to consider accessibility and the needs of all potential users. A travel chain refers to a journey from point A to point B, which may consist of one or more different means of transport [18]. Ideally, it should be possible to arrange and pay for entire travel chain from one service provider. The travel chain may also have hubs, e.g., travel centers and train stations, where passengers change from one means of transport to another. In the optimal case, the passenger gets the mobility services she/he needs from door-to-door based on the principle of one payment and one ticket. The transport services are meant to work together seamlessly for all passengers, and real-time information about the progress of the journey is also available during the trip.

An accessible travel chain can be defined as a continuum consisting of accessible services, physically accessible, and multi-sensory guided routes, stops, means of transport, and station spaces, which enable all passengers to travel as independently, smoothly, and barrier-free as possible.

What is meant by the essential accessibility information of travel chain? According to the EU’s directive (2019/882) [19] and the Act on Transport Services (107/2023) [20], essential accessibility information refers to information in digital form provided on websites and mobile applications about available services and assistance, in addition to intelligent ticketing systems, accessibility of the infrastructure and built environment surrounding the transport services, accessibility of equipment, equipment that facilitates the passenger's access to vehicles, available interaction with the driver, and access to real-time travel information.

B. MaaS Possibilities and Challenges

The digitization and proliferation of Mobility as a Service (MaaS) are expected to create new user-oriented opportunities, paving the way for the development of universally designed transport services [13][21]. MaaS is defined as "A type of service that, through a joint digital channel, enables users to plan, book, and pay for multiple types of mobility services" [13]. Originating from Intelligent Transportation Systems (ITS) [22], MaaS is intricately intertwined with the development of sustainable transport systems as a whole.

MaaS platforms aim to integrate multiple transport modes, various payment options, and diverse technologies, offering user-centric and user-sensitive mobility services through a single interface. While the goal is to make travel chain services accessible to everyone, several concerns arise. The increasing digitization of service sales and information provision may exclude some passengers who lack digital skills or whose access to digital devices is limited. Ensuring that accessibility information about mobility services and transport infrastructure is effectively transferred from information administrators to MaaS operators and ultimately to passengers remains a challenge [23]. As mobility services and their purchase become increasingly dependent on online platforms, there's a growing need for these digital services to be accessible to all users, including those with disabilities and rather modest digital skills. With new actors emerging between customers and transport operators, it's crucial to maintain up-to-date databases that convey comprehensive accessibility information about the entire travel chain to customers.

The creation of MaaS across different regions faces numerous challenges spanning technical, regulatory, economic, and social dimensions. Essawy (2024) highlights the challenge of diverse data formats used by different transport operators and regions, making seamless integration into a unified system difficult [15]. Ydersbond et al. (2020) point out that many existing transport systems rely on outdated technology, which is not easily compatible with modern MaaS platforms and unsuitable for integration [24]. Technical infrastructure varies significantly across regions. Ydersbond et al. (2020) note the substantial disparities in digital infrastructure between urban and rural areas, affecting the uniform implementation of MaaS [24]. Russo (2022) emphasizes that many transport systems lack the capability to provide real-time data, which is crucial for effective MaaS operations [25]. User adoption and behavioral change present further challenges. Silvestri (2021) observes that many users are accustomed to traditional transport modes and may be reluctant to switch to a new, integrated system [26]. Essawy (2024) adds that varying levels of digital literacy among different demographic groups can affect the adoption of MaaS platforms [15].

From a political and public sector perspective, the implementation of MaaS faces additional challenges. Public sector discussions and negotiations regarding service integration and contracts are often time-consuming processes. However, the complexity of integrating various transport modes, payment systems, and applications within this framework presents significant challenges. For instance, during a typical 15-minute city trip, users might need to switch between multiple applications and transport modes, raising questions about seamless integration, user experience, and payment methods.

When MaaS offers significant potential for improving mobility and accessibility, its successful implementation requires addressing a complex array of challenges. These range from technical and infrastructural issues to user adoption and accessibility concerns, as well as political and economic considerations. The integration of MaaS into city necessitates a comprehensive, inclusive approach to development and deployment, involving close collaboration between public and private sectors to create systems that are not only technologically advanced but also equitable, sustainable, and aligned with broader city development goals.

C. Barriers to Passengers' Movement and Functioning in the Travel Chain

Concerning accessibility in travel chains, Mwaka et al. (2024) [15] reviewed 34 articles on the subject to identify physical and social barriers, and facilitators in the travel chain, and to highlight issues related to lack of confidence or self-efficacy and reduced satisfaction when PwDs and older adults were using public transport. The results are organized in relation to the phases of the travel chain. The most common barriers found by the authors are described in the following. (1) *In relation to travelling to or from a public transport stop or station* were long walking distance, irregular walking surfaces, narrow pathways, branches hanging in pathways, small holes, poor design of curb cuts, difference in levels, steep side gradients on pathways, low contrasts in surface changes, combined pedestrian and cycling lanes, grey posts on pathways, crossings with traffic lights but no auditory signals, short walking times for crossings at traffic lights, traffic from two directions, turnstiles without sound modules to provide information about remaining balances on travel passes, crossing busy streets, lack of sidewalks, road works, lack of pavements, and a lack of low curbs. The most common barriers (2 In relation to waiting at the stop or station information was found to be unavailable in terminals or bus stops, drivers did not stop to let people board the bus, there was poor platform design and lack of signage, or signage too bright and glargine, there were levels of noise, lack of visual announcements on trains, narrow bus stops, no weather protection or shelters, no seats or inadequate seats, many buses stopping at the same bus stop, lack of timetables, small text on timetables, poor visibility on monitors, incorrect information, difficult to interpret information, no information about routes in service, no information provided in braille, the presence of stairs in railway stations, broken elevators or escalators. (3) *In respect to boarding and getting off the public transport*, the most common barriers were related to ramps, including lack of ramp, inoperable ramps, steep slope for ramp use, and ramp deployment angle (≥9.5°). (4) *In respect to the public transport vehicle*, the most common barriers related to the presence of steps at the vehicle entrance. (5) *Other common issues related to public transport use* included inability to navigate public system, lack of confidence in the use of public transport, lack of knowledge of public transport network, and fear of injury related to public transport.

III. METHODOLOGY

A. Identifying the Research Question

The research question of the study is to examine what kind of essential accessibility information on public transport travel chains is offered and how it is offered, as well as how the information meets the accessibility information needs of people with various mobility and functional disabilities.

The research is conducted in three phases, and each has its own target. (1) The first phase focuses on mapping the accessibility of mobility services, service processes, travel chains and hubs from the point of view of persons with temporary or permanent impairments, with the target of acquiring knowledge about what kind of accessibility information about the public transport travel chain is offered and how. (2) Based on the mapped results, the second phase focuses on defining the critical accessibility information about mobility services, service processes, nodes and infrastructure included in the travel chain from the user perspective and in relation to official sources of essential accessibility data. (3) The third phase identifies the actors within the MaaS architecture responsible for facilitating barrier-free movement in the city and region of Riihimäki. This phase focuses on study group used applications. This article reports on the results of these three phases, along with insights gained regarding the use of smartphones by PwDs when accessing public transport services.

B. Description of Study Area and Participants

The case study takes place in southern Finland, in the City of Riihimäki and the region. Riihimäki, has 30,000 inhabitants, and is a typical medium-sized city in Finland. As such it is an example of availability of accessibility information concerning the travel chain is realized in a smaller city, like most Finnish cities. Its distinctive features, however, are that it has a dense urban structure and a busy train station. The entire station-zoned urban area is within a three-kilometer radius of the railway station, where 97% of the population lives. Riihimäki has a Sustainable Mobility Program [27], with significant investments in the urban environment to increase sustainable modes of transportation. Sustainability refers to environmentally and socially favorable modes of transportation that are economical, smooth, safe and improve the health of the person moving. City dwellers are encouraged to use sustainable modes of transportation, such as walking, cycling, using public transport and travel chains, as well as carpooling.

The public transportation consists of regular local bus lines, small on-demand buses with door-to-door services, service lines on standard routes and taxi services for disabled. All local and on-demand buses have low floors. The most important hubs are the railway station, the bus station, and the expressway connection to regional buses. There is interconnectivity between the hubs and regions. Regional and local buses, including on-demand buses, feed regional, long-distance, and international trains.

Public transport uses a mobile application and an online version of the route application *Routes and Tickets* to reserve and pay for tickets and travel chains. The application can also be used to report transport needs for wheelchairs, strollers, and rollators. In addition, there is an option to reserve and purchase tickets by phone. Another route guide in use on the Internet and as a mobile application, especially for travel chains including train journeys, is provided by *VR Matkalla*.

The primary target group of the study are persons with temporary or permanent mobility and/or sensory challenges due to illness, aging, and/or disability (PwD). A sample of thirteen volunteer representatives of the target group from local and national disability organizations participated in the study.

TABLE I. TARGET GROUP

Target group deviation for different diseases and conditions			
Disease/Condition	***Count of PwDs***	***Assistive Devices/Services***	***Information and Communication Technology***
Physical or motor disability	7	Wheelchair (1x), Occasional Electric Wheelchair (1x), Electric wheelchair (4x)	Computer, Smartphone
Visual impairment, Blindness	3	White cane (3x), Guide dog (1x)	Computer, Smartphone
Visual impairment, Low Vision	2	None	Computer, Smartphone
Aging with Temporary physical difficulties	3	Assistant	Computer, Smartphone

The mobility challenges faced by PwDs are highlighted in Table I, which summarizes the diseases and conditions affecting them. This table provides a comprehensive overview of the study's sample, showcasing the diversity of conditions and challenges encountered. In addition, the material shows the differences due to disability and functional capacity in relation to aids and services used by PwDs and information and communication technologies. The age range of participants was 40-82 years. Thirteen of the participants currently use public transport independently and two with the accompaniment of another person.

All the participants had computer and Internet access at home, and owned a smartphone, but their skills in terms of searching for information on the Internet as well as using a smartphone varied. Another indirect target group are public transport authorities, operators, companies, and associations that provide mobility services in Riihimäki and the region.

C. Data collection

To define the necessary essential information, from the point of view of a PwD, information was needed on which accessibility information is perceived as usable and useful before and during the trip. Data collection took place between February 2023 to December 2023 (around eleven months). The data collection was carried out using the snowball sampling method. For participants to be eligible, they had to be current public transport users. Local and regional disability councils and organizations representing disability groups were contacted to invite their members who matched the criteria to participate. Organizations were given email addresses and phone numbers so that potential participants could contact the researcher directly, or the volunteers' contact information was provided to the researcher, who contacted then the volunteer. Once an individual participated, they were asked to invite other people they knew. This approach ensured potential participants of the research through personal endorsements.

The goal was to recruit at least 12 participants so that the thematic saturation of the information and the validity of the data were realized [28]. Small samples have been found to be quite sufficient in providing complete and accurate information within a particular cultural context, as long as the participants possess a certain degree of expertise in the domain of inquiry [29]. The individuals in our purposive sample shared common experiences, and these experiences comprise perceived and experienced truths. PwDs talked about the challenges of finding necessary and accurate accessibility information regarding routes, junctions, and vehicles related to their travel chains during the planning phase. For example, they questioned whether the elevator at junctions would be functioning. Fear and distrust of data concerning a seamless travel chain are realities in the daily lives of PwDs and are thus reflected in the data.

The data collection was originally planned to be carried out through a self-administered online user preference survey, developed by using the online survey tool Forms by Microsoft. After the first workshop organized for visually impaired people, it was obvious that simply answering the survey independently online would not be a sufficient way to collect the data. Due to reported difficulties with the use of computers by the participating PwDs thematize interviews based on original questionnaire were implemented.

Planning the travel chain (1): The first phase of the research began by examining how the participants typically planned a journey chain before traveling. The travel chain consisted of leaving from the origin of the journey to the destination with the required vehicle exchanges at hubs. The thematic interviews and travel chain planning were done in eight workshops. At each workshop, the participants explained their travel chain planning processes and justified their choices. During the discussions, the researchers asked the participants clarifying questions as needed. All conversations were recorded. The content of the recordings was analyzed using content analysis methods. Each volunteer participated in 2-6 workshops and interviews, depending on the number of trips they made. Planning was done on the Internet with a focus on access to passenger accessibility information, available information about barrier-free mobility services, service processes, and accessible vehicle exchanges at hubs. The purpose was to understand the methods PwDs used to search for accessible travel information and how they accessed the different information they required through various digital tools, websites, or by calling customer service.

On the journey implementation (2), data was collected by retrospectively recalling the step-by-step implementation of the trip, and by observing the implementation of the trip with jointly realized trip chains. These observations were collected during thematize interviews, by reading travel diaries, and by implementing a variety of monitoring methods, e.g., shadowing, and passive observation, during field journeys, and after the journey with theme interviews based on recalling the travel experiences retrospectively from the entire travel chain including the various transport nodes. In connection with the workshops, essential accessibility information was also defined from the perspective of PwDs. Observations and thematic interviews in connection with the workshops were used to find out how accessibility information was present when PwD passed through the different stages of the travel chain and where the problem areas in terms of accessibility were. PwDs, the authorities and other stakeholders were invited to a joint seminar at the end of this data collection phase, where the results were presented, and the views of all parties, and conclusions from the results were heard. The aim of the seminar was to deepen the common understanding of accessibility information needs and strengthen the reliability of the results.

The second phase of data collection compared the mapped critical essential accessibility needs with the officially defined accessibility information standards. To enable a comparison, the official data sources in use were assembled by interviewing stakeholders and authorities responsible for the data sources. Comparing these elements began in the workshops after the actual journey experiences of the PwDs. The most critical accessibility information of PwDs' travel experiences, the mobility services, service processes, stops, vehicles and vehicles exchange at nodes, and multisensory guidance were analyzed. The identified essential accessibility information needs were compared with the information available through route guides and with the official digital data sources behind them. A second seminar with the same purposes was organized at this point and thus all concerned contributed to the analysis process.

In the third phase of our study, we evaluated services that integrate multiple data sources to facilitate travel chain planning and identify suitable travel options for PwDs. These services were examined as MaaS solutions, which are essential for making travel chains more accessible and easier to navigate for all users, particularly those with disabilities.

Our research emphasizes the crucial role of integrating MaaS with NAPs. NAPs should serve as comprehensive repositories of transportation information for various cities, providing a solid foundation for MaaS services. This integration is a critical factor in enhancing the usefulness and effectiveness of MaaS solutions, ensuring the seamless incorporation of diverse data sources.

To gather relevant information, we focused on services actively used by our target group of PwDs. Our methodology involved a thorough examination of each application's accessibility features and an analysis of how PwDs utilize these services in their daily lives. This approach allowed us to gain valuable insights into the practical usability and effectiveness of MaaS solutions for users with various disabilities.

When evaluating the real-world application of these services, we aimed to identify both the strengths and areas for improvement in current MaaS offerings. This user-centric approach provides a more nuanced understanding of how well these services meet the specific needs of PwDs and highlights potential areas for future development in making travel more inclusive and accessible.

IV. RESULTS

A. *Experienced challenges of the travel chain*

During the analysis process, the results from the questionnaires, theme interviews, workshops, observations, and experiences from physical excursions were classified based on the content and theme (Table II). This table provides a comprehensive overview of all the information gathered during the different phases of the travel chain.

TABLE II. CHALLENGES IN THE TRAVEL CHAIN

Challenges of travel chain phases	
Preliminary phase	***Implementation phase***
Travel booking challenges	The challenges of means of transport
Challenges of needed accessibility information of routes, junctions, and vehicles	The need for information while traveling
Lack of customer services and challenges of assistance services	The challenges of assisting
The challenges of reserving, buying, and getting hold of a ticket	The challenges of nodes

During the trip planning phase, the need to reduce various uncertainties regarding the trip was highlighted. Travel booking challenges of the preliminary phase were related to the selection of the most suitable route options, and vehicles' choices, as well as keeping the number of hub changes as few as possible. Optimal choices of the travel chain were made based on available accessibility information, e.g., train trips were preferred instead of long distance buses, and the distance was important between the arriving and departing platforms at transport nodes. Other important aspects, included finding a suitable ticket for journeys and purchasing it easily, allowing enough time for vehicle changes at nodes, providing sufficient information about vehicle accessibility, and information about assistance services. These elements were considered crucial for ensuring a sense of safety while traveling. The most important aspect discussed by the interviewed PwDs was traveling safety provided by the preliminary information which was seen as lacking in many cases.

During the implementation phase, identified critical needs included the availability of assistance service points, certainty of assistance, and access throughout the entire travel chain. It is crucial to consider how to access information in case of unexpected changes in the travel chain. Tracking the progress of the trip, tactiles, multisensory guidance, and sound beacons were recognized as essential for individuals who were blind or visually impaired.

B. Narrow view of essential accessibility information in data sources

Accessibility data was examined through various data sources and was utilized to gather information to analyze different interfaces. The formats of these sources vary, impacting how the data is presented for diverse uses and its accessibility in machine-readable formats. This study concentrates on accessibility information which is, typically available on service provider websites, although locating this information can be challenging. In Finland, the General Transit Feed Specification (GTFS) is a prevalent method for presenting travel information and showcasing trip details, routes, and stop information in a machine-readable format [30]. However, GTFS-format data primarily represents singular aspects such as wheelchair-accessible locations, vehicles, paths, or stops and does not address the breadth of accessibility difficulties.

TABLE III. USED DATA SOURCES AND FORMATS

Data sources for accessibility information present		
Data source name	***File format***	***Accessibility***
GTFS	Data presented in CSV files which are collected in a ZIP file.	wheelchair accessible, wheelchair boarding
NAP	Data presented in GeoJSON. It utilizes the JSON file format for representing geographical data structures.	boarding-assistance assistance-dog-space, accessible vehicle, low-floor, step-free-access, suitable-for-wheelchairs, suitable-for-stretchers
NeTEx	Data is presented in XML file format which is a markup language for organizing and storing data in a structured format.	Wheelchair access, Step free access, Escalator free access, Lift free access, Audible signs available, Visual signs available
VR	Website	Written information
Matkahuolto	Website	Written information
Opas.matka.fi	Website	Written information

Information must be presented in multiple ways to cater to diverse needs. This necessitates employing various formats and methods to ensure information is accessible digitally and that physical environment accessibility information is conveyed throughout the entire travel chain. The varied data formats are depicted in Table III. These data sources were analyzed to reveal potential accessibility information within the data sources. The collection of this data was guided by the requirements identified from the interviews, which focused on gathering preliminary information and specifics about the trip.

To ensure comprehensive accessibility, it is crucial to address the diverse needs of users by presenting information in varied formats and using multiple methods. This strategy ensures that accessibility information is available in digital formats and is effectively communicated throughout the entire travel process, thereby enhancing the overall user experience. The analysis of different data formats, as detailed in Table III, facilitates a thorough examination of potential accessibility information within the data sources.

Furthermore, the data collected from these data sources was specifically tailored to meet the requirements identified during the interviews, which focused on preliminary information and trip specifics. Incorporating insights from these interviews, the study seeks to improve the understanding of accessibility challenges and opportunities within the context of various interfaces and data structures. This comprehensive approach is vital for developing inclusive and user-friendly solutions that meet a wide range of accessibility needs in transportation and travel services.

The data formats present accessibility information at a basic level. For example, the common GTFS format categorizes accessibility in three stages with values ranging from 0 to 2, indicating the level of accessibility for different stages in the travel nodes. These values represent the stage of accessibility as follows for stops:

- 0 = No accessibility information
- 1 = Some vehicles at this stop can be boarded by a rider in a wheelchair.
- 2 = Wheelchair boarding is not possible at this stop.

For trips, the information is as follows:

- 0 = No accessibility information for the trip.
- 1 = Vehicle being used on this trip can accommodate at least one rider in a wheelchair.
- 2 = No riders in wheelchairs can be accommodated on this trip.

In Riihimäki's public transportation system, GTFS files indicate an accessibility level of 0, which means there is no accessibility information available for any trips or stops in the city of Riihimäki, which is a clear deficiency according to the information mentioned earlier about the obligation to provide essential accessibility information by the ministry [6]. The lack of accessibility information results in the inability to search for wheelchair-friendly or accessible options for trips in Riihimäki, posing challenges for finding suitable public transportation options for PwD.

Travel chain accessibility information is distributed through various sources, and operators collect this data for the NAP. The instructional materials provided by the NAP are intricate, and the guidelines for submitting information suggest that accessibility details are to be filled in multiple fields. However, the instructions lack clarity on how and where the information should be entered.

During the interviews with travel service providers, it became evident that they possessed a wealth of information. Nevertheless, there is a lack of a standardized method for presenting this information on their websites and for submitting accessibility data to the NAP. Improved guidelines are needed to ensure that the information is effectively filled in, benefiting both authorities and passengers.

During the data collection process in this study, there was a need to map various data sources and explore methods for presenting accessibility information and data formats. Among the materials investigated, the Network Timetable Exchange (NeTEx) format emerged as particularly noteworthy for its ability to offer a more comprehensive range of accessibility information compared to GTFS. NeTEx can organize collected data in a manner that allows for more detailed accessibility information, including the presentation of information at different stages within the travel chain. This format provides an opportunity to conduct an accessibility assessment, highlighting the accessibility characteristics of various entities utilized by passengers and outlining limitations in six distinct accessibility needs [30]:

- Wheelchair Access: indicates whether the service or location is accessible for individuals using wheelchairs.
- Step Free Access: indicates whether some steps or obstacles could hinder access for passengers.
- Escalator Free Access: indicates if escalators are available for passenger use.
- Lift Free Access: indicates the presence of lifts for vertical transportation.
- Audible Signs Available: indicates whether audible signs or announcements are provided for passengers.
- Visual Signs Available: indicates whether visual signs or information are provided for passengers.

The comparative analysis of NeTEx and GTFS models reveals significant differences in their approaches to accessibility data management in public transportation systems. While GTFS, widely used in Finland, employs a simplified three-tier classification system (0-2) primarily focused on wheelchair accessibility, NeTEx offers a more comprehensive and sophisticated framework through its XML-based structure. Unlike GTFS's limited scope, NeTEx incorporates six distinct accessibility parameters: wheelchair access, step-free access, escalator-free access, lift-free access, audible signs, and visual signs availability. This expanded framework enables more detailed accessibility assessments and better supports diverse user needs throughout the entire travel chain. The structured data organization in NeTEx facilitates improved data interoperability and machine readability, allowing for more nuanced representation of accessibility features at various stages of the journey. This comprehensive approach makes NeTEx particularly valuable for developing inclusive transportation systems that can effectively address the diverse accessibility requirements of all users, surpassing the basic categorization limitations inherent in the GTFS model.

C. Enhancing Travel Accessibility through MaaS Integration

MaaS integration presents a valuable solution for achieving high levels of accessibility and inclusivity in travel. Our research demonstrates that MaaS significantly aids in the information search process, enabling users, including PwDs, to find suitable travel chains. Through the diverse services and integration possibilities offered by MaaS, it becomes feasible to create personalized user profiles and purchase tickets that effectively meet the needs of PwDs, ensuring their requirements are adequately addressed within the transport system.

To illustrate the current landscape of MaaS applications and their accessibility features, we conducted an exploration of services commonly used by PwDs. Table IV presents our findings, demonstrating the overall accessibility, MaaS integration level, and specific features provided by each service.

To assess the MaaS integration level presented in Table IV, a three-tier metric was created. This metric allows for the categorization of service integration levels and the evaluation of possibilities to find suitable travel chain options. The MaaS integration levels are defined as follows:

1. Low Integration: Services at this level have minimal connection to the MaaS ecosystem. While they may provide valuable assistance to PwDs, they operate largely independently of other transportation services. These services might offer specific functionalities like navigation aids or accessibility information but typically lack integration with booking systems or other transport modes.
2. Medium Integration: Services with medium integration have established some connections to the MaaS ecosystem. They may offer features that link to other transportation services or provide limited multi-modal journey planning. However, they might lack full integration in areas such as unified payment systems or comprehensive real-time data across all available transport options.
3. High Integration: Highly integrated services are deeply connected to the MaaS ecosystem. They typically offer comprehensive journey planning across multiple modes of transport, real-time updates, integrated booking and payment systems, and seamless transitions between different transportation providers. These services often act as one-stop-shops for planning, booking, and managing entire journeys, regardless of the transport modes involved.

TABLE IV. MAAS APPLICATIONS AND THEIR ACCESSIBILITY FEATURES

Services Used by PwDs and MaaS Access				
Application	***Type of Service***	***Features for PwDs***	***MaaS Integration Level***	***Accessibility Level***
VR Matkalla	Travel Planner	Travel chain building, User profiling, Limited: Combined agreement, Tickets	High	High
Reitit ja liput (Trips & Tickets)	Travel Planner	Travel chain building, Address-to-address routing, Limited: First/last mile solutions, Tickets	Medium	Medium
BlindSquare	Accessible Place Simulation and Navigation Aid	Place simulation, Indoor navigation, Outdoor navigation, Limited: on-demand sound beacons, Nearby transport info, Platform guidance, Tickets	Medium	High

The accessibility metrics presented in Table IV are formulated from a combination of PwD user experiences, service provider accessibility policies, and compliance with Web Content Accessibility Guidelines (WCAG) standards, as required by the Finnish government [31][32]. We evaluated the applications' multi-format usability, including screen reader compatibility, adjustable text sizes, and navigation simplicity. The accessibility levels are defined as follows:

1. Low Accessibility: Services at this level offer basic functionality but have limited features specifically designed for PwDs. They may have some accessibility considerations but fall short in providing comprehensive support for various types of disabilities. These services might be usable by some PwDs but often require significant effort or additional assistance.
2. Medium Accessibility: Services with medium accessibility have made notable efforts to accommodate PwDs. They include several features designed to assist users with different disabilities, such as screen reader compatibility, adjustable text sizes, or simple navigation for mobility-impaired users. While these services are generally usable by many PwDs, they may still have some limitations or areas for improvement.
3. High Accessibility: Highly accessible services demonstrate exceptional consideration for PwDs across various disability types. They typically offer a wide range of accessibility features, such as full screen reader support, voice control, customizable interfaces, and detailed accessibility information for physical locations. These services are designed with universal access in mind and can be used independently by most PwDs without significant barriers.

D. *MaaS and NAP Integration*

Our research uncovered significant gaps in how MaaS platforms incorporate data from NAPs. The structure of NAPs typically consists of a Catalog, which contains Metadata describing the available datasets, and the actual Datasets themselves. In the realm of public transportation, these datasets are particularly rich and diverse, encompassing static information like routes and schedules, as well as dynamic data such as real-time vehicle locations and service disruptions [33].

Upon examining the detailed metadata from the NAP covering the City of Riihimäki area, we identified notable gaps. These findings highlight the need for NAP information, particularly in Riihimäki, to be at a level that enables effective MaaS service integration. When NAPs function as centralized platforms for transport-related data, they allow MaaS providers to access real-time information easily, thereby enhancing the quality and reliability of services offered to users [34].

However, there is a notable lack of standardization in data exchanges and real-time data delivery from transport systems, which hinders large-scale system integration. Addressing these challenges is crucial for realizing the full potential of MaaS and improving accessibility for all users, especially PwDs.

The integration of MaaS with NAPs significantly improves the user experience by facilitating seamless journey planning, booking, and payment across various modes of transport. Users benefit from a more convenient and efficient travel experience, leading to increased satisfaction and usage. By accessing comprehensive data, MaaS providers can optimize routes, reduce travel times, and improve service efficiency, resulting in cost savings for both providers and users.

Improved accessibility is another significant benefit of this integration. Integrated systems can offer tailored solutions for different user groups through profiling, including PwDs, by providing more accessible and inclusive transport options. The purpose of integrating MaaS with NAPs is to serve as a centralized data hub. NAPs collect, store, and distribute transport data, supporting the efficient functioning of MaaS by ensuring that all stakeholders have access to consistent and up-to-date information.

The integration of MaaS and NAPs holds great promise for enhancing travel accessibility and inclusivity. By addressing current gaps and standardization issues, we can create a more seamless, efficient, and accessible transportation ecosystem that benefits all users, particularly those with disabilities.

E. *Implementation Framework for Accessible MaaS Integration*

The implementation of accessible MaaS requires a comprehensive architectural framework that addresses both technical integration and accessibility requirements. This framework, illustrated in Figure 1, establishes a hierarchical structure that enables seamless information flow while ensuring accessibility remains a core consideration throughout the system.

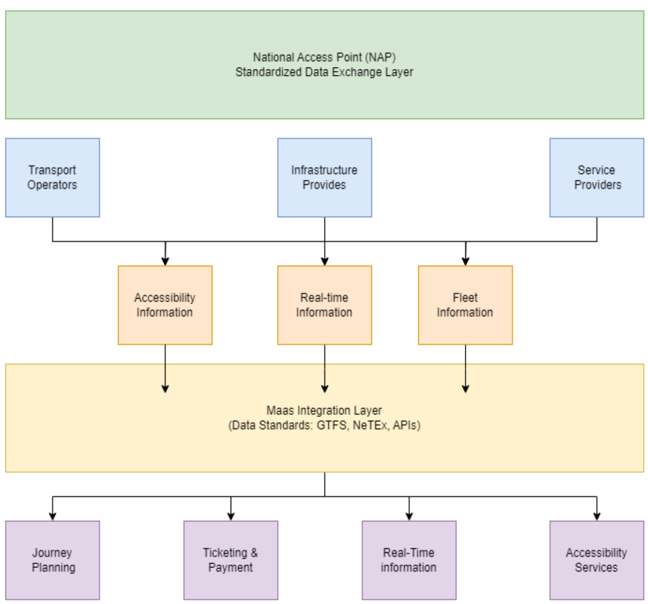

Figure 1. Architectural impelementation plan of MaaS integration service.

At the highest level, as shown in the topmost layer of Figure 1, NAP serves as the cornerstone of the architecture, providing a standardized data exchange layer that facilitates cross-border interoperability and consistent information sharing. This overarching framework ensures that accessibility information maintains its integrity across different systems and jurisdictions, supporting the broader goal of inclusive mobility solutions.

The architecture's data source layer (depicted in the second tier of Figure 1) concludes various stakeholders, including transport operators, infrastructure providers, and specialized service providers, each contributing essential information to the ecosystem. Transport operators provide crucial details about vehicle accessibility features and operational schedules, while infrastructure providers maintain comprehensive information about physical facilities and their accessibility characteristics. Service providers complement these primary data sources by offering specialized accessibility information and assistance services, creating a robust foundation for inclusive mobility services.

Central to the architecture, as illustrated in Figure 1's middle layer, is the MaaS Integration Layer, which employs established standards such as GTFS and NeTEx, alongside modern APIs (Application Programming Interface), to ensure seamless data interchange. This integration layer serves as a crucial mediator, transforming diverse data formats into standardized structures that support accessibility service delivery. The implementation of this layer requires careful consideration of data models that can sufficiently represent accessibility features while maintaining compatibility with existing transportation data standards.

The service layer, shown at the bottom of Figure 1, represents the connection of the integrated data and services, manifesting in four primary functional areas: journey planning, ticketing and payment systems, real-time information services, and specialized accessibility services. Journey planning incorporates accessibility considerations directly into route optimization algorithms, ensuring that suggested routes align with users' accessibility requirements. The ticketing and payment systems are designed with universal access principles, while real-time information services provide crucial updates about service disruptions and accessibility status changes. Dedicated accessibility services within this layer coordinate specialized assistance and support, ensuring that users with specific needs receive appropriate accommodation throughout their journeys.

The vertical integration emphasis shown by the connecting arrows in Figure 1 illustrates the continuous flow of information from data sources through to end-user services, ensuring that accessibility considerations flow in every aspect of the system. This comprehensive approach supports the development of truly inclusive mobility solutions that can adapt to diverse user needs while maintaining high standards of service delivery.

This implementation framework represents a significant step forward in the development of accessible transportation systems, providing a structured approach to integrating accessibility considerations throughout the MaaS ecosystem. Through careful attention to standards, stakeholder needs, and user requirements, the framework supports the progressive realization of truly inclusive mobility solutions that serve the diverse needs of all transportation system users.

V. Discussion

The analysis of accessibility information in various data sources reveals several aspects that require further clarification and definition. The challenges faced by PwDs in utilizing accessibility information can be categorized into six major themes for improvement, addressing information gaps in the preliminary phase, during trips, throughout the travel chain, and in MaaS possibilities:

- Improving accessibility information: providing clear and comprehensive details about the accessibility of different modes of transportation, such as stair heights, ramp availability, and the location of assistance points, is essential for helping passengers with disabilities plan their journeys effectively.
- Enhancing assistance services: it is crucial to ensure that assistance services are easily accessible and that the ordering process is clear and seamless. Additionally, having assistants available at critical locations like stations and trains is important.
- Utilizing technological solutions: offering practical mobile applications to passengers that provide real-time information on transportation accessibility, schedules, and ticket reservations can significantly enhance independent travel for passengers.
- Collaboration among stakeholders: close collaboration among public transportation operators, tourism services, and associations for PwDs is necessary to promote accessible travel. Through collaboration, better solutions and services can be developed for passengers with disabilities.
- Improving guidance accessibility: ensuring that accessibility information is available in various formats, such as tactile pathways, easy-to-read maps, and providing Braille, and audio guidance. It is crucial to ensure all passengers can access the information they need.
- Customer services and location accessibility: ensuring the availability of customer service locations, providing location-based information about the traveling center building, and determining the availability and specifications of accessible routes and services, e.g., toilet spaces are important considerations for enhancing accessibility for all individuals.

The concept of an accessible travel chain is a matter of social equality and justice. Barrier-free travel chains ensure that all people, including people with reduced mobility, such as people in wheelchairs, visually impaired, or hearing-impaired, can travel on public transport as independently as possible and without barriers. A barrier-free travel chain is smooth, safe, and effortless for everyone. For example, physically barrier-free stops, stations, elevators, and multi-sensory signs, make traveling from one place to another easier and smoother. Raised platforms and low-floor train carriages reduce the risk of tipping over and enable easy access to and from the train. The ease and comfort of traveling improve everyone's travel experience.

In relation to MaaS services, e.g., within digital journey planners and route guides, more comprehensive data access and more advanced combination services as well as advanced user profiling and user sensitivity choices could in the future help in the rerouting of the travel chain when facing unexpected challenges during the journey. During the research, user profiling options were so far modest, especially for the passenger himself.

The evolving EU regulations and standardizations significantly impact the development and integration of MaaS solutions into travel chains. These updates influence how PwDs utilize technological solutions, including combination services and MaaS features. For instance, services like *VR Matkalla* facilitate the creation of travel chains by combining agreements and offering routes and tickets in collaboration with *Matkahuolto*. They address challenges in demand-responsive transportation, particularly in the first and last 15 minutes of travel, providing door-to-door solutions. Similarly, BlindSquare assists visually impaired users by simulating unfamiliar places and providing information about nearby public transport services and platforms, benefiting PwDs with digital skills.

In the realm of information sharing, GTFS and NeTEx are the most common formats for presenting metadata from systems and various nodes. However, the level of detail in accessibility information provided by different operators and service providers varies, creating challenges due to the lack of clear guidelines on reporting physical nodes.

The adoption of similar standards for collecting transportation, travel chain, and infrastructure information across European countries enhances the accessibility of these chains and facilitates cross-border travel. This harmonization, supported by NAPs, opens numerous possibilities to improve accessibility information for all travelers, including PwDs, catering to diverse user needs. The integration and development of NAPs, along with perspectives on NeTEx and European development, play a crucial role in ensuring that data integration and accessibility are prioritized in the evolving landscape of MaaS solutions.

It is important to note that for some services it has been possible to create only a minimal connection to the platform built with the MaaS concept, even though they could offer, e.g., valuable navigation assistance or accessibility information. These thinly connected services do not integrate with the ticket reservation systems of other modes of transport, but only provide a link to another service. The integration possibilities of these services are limited by overly complex agreements and conflicting business models between the parties.

By these means the development of accessible MaaS solutions requires a multifaceted approach, addressing technological, infrastructural, and collaborative challenges. When focusing on these key areas, there is possibilities to go towards creating a more inclusive and efficient transportation system that truly serves the needs of all users, regardless of their abilities.

VI. Conclusion and Future Work

The landscape of MaaS in Finland is rapidly evolving, bringing both opportunities and challenges. A comprehensive analysis of accessibility information needs, compared with existing databases and data sources, reveals significant areas for improvement in public transport and travel chain development. This insight is crucial for enhancing the travel experience for all users, particularly those with diverse needs.

Legal frameworks and ethical guidelines emphasize the importance of equal treatment for all passengers, underscoring the need to accommodate various individual requirements in the development and execution of public transportation systems. However, the increasing reliance on digital platforms for mobility information and service purchases presents new challenges. As personal services at stations and service points diminish, ensuring universal access to mobility services becomes more complex. This shift particularly affects individuals with limited digital skills, those requiring assistive technologies, and people who face challenges in obtaining digital travel information.

The usability of MaaS applications is a critical concern. Many users face a steep learning curve due to the lack of clear, user-friendly instructions. They often struggle to navigate complex interfaces, understand various transport options, and manage intricate booking and payment systems. Most operators expect users to learn through self-exploration, which can be daunting, especially for those less familiar with digital technologies. While efforts to improve digital information flows are essential, it's equally important not to neglect the development of traditional customer service aspects.

In this complex ecosystem, clearly defining areas of responsibility among various stakeholders is crucial for seamless operation. Key players in Finland's MaaS landscape include cities, transport operators, service providers, and municipalities. Each entity has distinct roles, yet their responsibilities often overlap, necessitating clear delineation and cooperation. Cities, for instance, play a pivotal role in MaaS implementation, being responsible for local transportation infrastructure, urban planning, and often operating or contracting local public transport services. They also set local transportation policies that significantly impact MaaS operations.

Collaboration among transportation service providers, cities, and other stakeholders is essential for developing solutions that facilitate effective communication, planning, and information gathering. This cooperation is crucial for meeting EU requirements for data collection from transport nodes. By leveraging up-to-date data, service providers can enhance their ability to offer suitable travel chains for everyone, PwDs.

The integration of data into centralized platforms, such as NAPs, can significantly enhance MaaS development. This integration supports the use of MaaS across multiple modes of transportation, promoting accessibility and compliance with standardization and legislation. It also facilitates the creation of seamless travel chains, improving the overall travel experience for all users.

As we move forward, it's crucial to balance technological advancements with inclusive perspective and Universal Design Principles. While digital solutions offer numerous benefits, they must be developed with consideration for all user groups. This includes providing comprehensive guidance on how to use MaaS applications effectively and ensuring that digital interfaces are intuitive and accessible to users with varying levels of technological proficiency.

The development of MaaS in Finland presents a multifaceted challenge that requires a holistic approach. By addressing accessibility needs, improving usability, fostering stakeholder collaboration, and integrating data effectively, Finland can create a more inclusive, efficient, and user-friendly mobility ecosystem. This approach not only enhances the travel experience for all but also sets a standard for sustainable and accessible urban mobility solutions worldwide.

Declaration of Conflicting Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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