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TOPICAL REVIEW

A Review on Disability-Inclusive Public Transportation: Current Barriers and Prospects

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ABSTRACT People with disabilities face significant barriers in using public transport, limiting their access to healthcare, employment, education, and daily life activities. A comprehensive review of existing research critically identifies these barriers, analyzes efficient interventions, and uses modern technology to create inclusive public transport systems that empower people with disabilities and foster a more equitable society. The current review systematically identifies the key barriers and prospects of disability-inclusive public transportation. It also highlights the policy shortcomings, accessibility gaps, and current technological advancements to foster inclusivity and improve mobility needs for disabled individuals. Searching scientific databases Scopus and Web of Science yielded 1100 articles; 35 met the inclusion criteria. The selected studies were conducted in various countries, emphasizing the topic's geographical importance. Several studies in the last five years indicated the topic's growing interest and potential impact. The present study categorized the key barriers into five types: inaccessible infrastructure, information and communication, attitudinal, economic, and safety and security. Case studies from diverse geographical and social settings correlated the barriers with the satisfaction levels of people with disabilities. The case studies highlighted the critical problems disabled people face that should be considered while designing successful transportation systems and travel chains. The study also illustrates the key features of a successful transportation system for disabled people based on best practices adopted worldwide. The prospects of using advanced technology, such as machine learning and modern imagery techniques, are also discussed.

INDEX TERMS People with disabilities (PWDs), sustainable urban mobility, inclusive public transportation, transport equity, urban spaces, physical disability, assistive technologies.

I. INTRODUCTION

Cities and governments are working to address the challenge of promoting public Transport [1]. However, people with disabilities remain one of the most marginalized groups in society and are unable to achieve the same level of mobility as people without impairments. It might be challenging to define disability in travel behavior studies since operational meanings differ, such as a longstanding health problem affecting travel ability, and individuals unable to transport themselves without special equipment or assistance. Since mobility is a crucial requirement for societal inclusion, people with disabilities regularly experience exclusion to the extent that some of them cannot complete routine journeys [2]. Policy and legal frameworks before 2006 often neglected the unique needs of disabled people, and international human rights agreements did not adequately address their rights. After the approval of the historic United Nations Convention on the Rights of Persons with Disabilities (UNCRPD) by the United Nations General Assembly on December 13, 2006, the state parties were required to put in place several equal access measures, including physical environment, transportation, information and communication technologies, and other public amenities and services in urban and rural

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regions, to guarantee the complete independence of disabled people in all facets of life. The all-encompassing strategy entails locating and removing impediments and hurdles to accessibility, encompassing edifices, roads, transit, schools, residences, healthcare facilities, offices, and information services, including electronic and emergency services [3].

Approximately 15% of the global population, equivalent to an estimated 1 billion individuals, experience some disabilities, making them the most significant minority worldwide [4], [5]. Many developed countries are dealing with issues associated with aged and disabled people [6]. The percentage of 65 or older persons is anticipated to double during the next 15 years, while 80 years or older will triple in the United Kingdom [7]. The percentage of people 65 or older in the United States is expected to double by 2060 [8]. In Hong Kong, the population of individuals aged 65 and above is expected to rise from 12% in 2015 to 25% in 2035. The simultaneous increase in average life expectancy and a corresponding decline in birth rates are responsible for this demographic transition [6]. Around 20% of the population of the United Kingdom is categorized as having some form of disability or impairment, and the bulk of these people, two-thirds of the afflicted demographic, are 60 years or older. Additionally, it has been noted that difficulties with movement and outdoor activities affect close to half of this community with disabilities or impairments. A similar analysis reported that 12.6% of the United States population faces disabilities, and 35.5% of people over 65 years old belong to this group [9].

About 80% of the disabled population lives in developing countries [10]. The majority of individuals with disabilities living in these countries are unemployed, indicating a concerning societal issue. Figure 1 presents the unemployment rate for disabled people across different countries in the Middle East, with Saudi Arabia having the maximum unemployment rate. A recent survey in 2017 revealed eight different types of disabilities for the male and female population, as shown in Figure 2; in contrast, the kind of disability shown in the alphabet, i.e., A denotes (communication and understanding with others), B (memory and concentration or cognition), C (difficult to walk or climbing stairs), D (with the use of audio aids), E (without the use of audio aids), F (personal care such as bathing, dressing or using the toilet), G (with the use of glasses), and H indicates (without using glasses) [11]. As for those who struggle with more than one of the eight categories, the survey shows that mobility issues like walking or climbing stairs affect 29.13% of the Saudi Arabian disabled population, with the following severity levels: mild (16.71%), severe (29.22%), and intense (54.07%). Subsequently, 24.15% of all Saudi individuals with impairments suffer from visual difficulty (vision). Among those with visual impairments, the severity can be categorized into three levels: mild (4.24%), severe (21.66%), and intense (74.10%). The least prevalent challenge of comprehension and communication affects 10.25% of all Saudi individuals with disabilities. Estimates place its intensity levels at 20.53% (mild), 26.25% (severe), and 53.22% (intense), respectively. In any case, public transport accessibility plays a crucial role, significantly impacting the well-being of people with disabilities. Unrestricted access to public transport can transform their lives, moving them from a dependent and isolated state to one that values social integration.

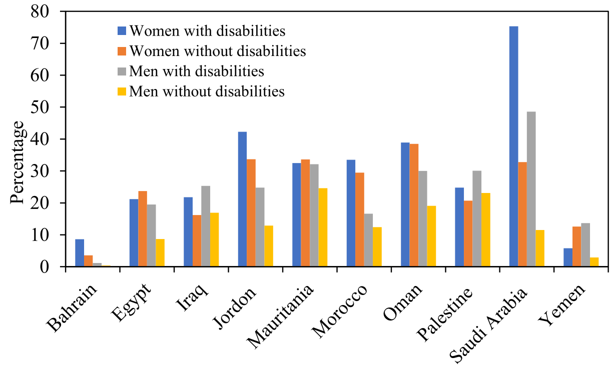


FIGURE 1. Rate of unemployment of disabled people across different Arab regions [12].

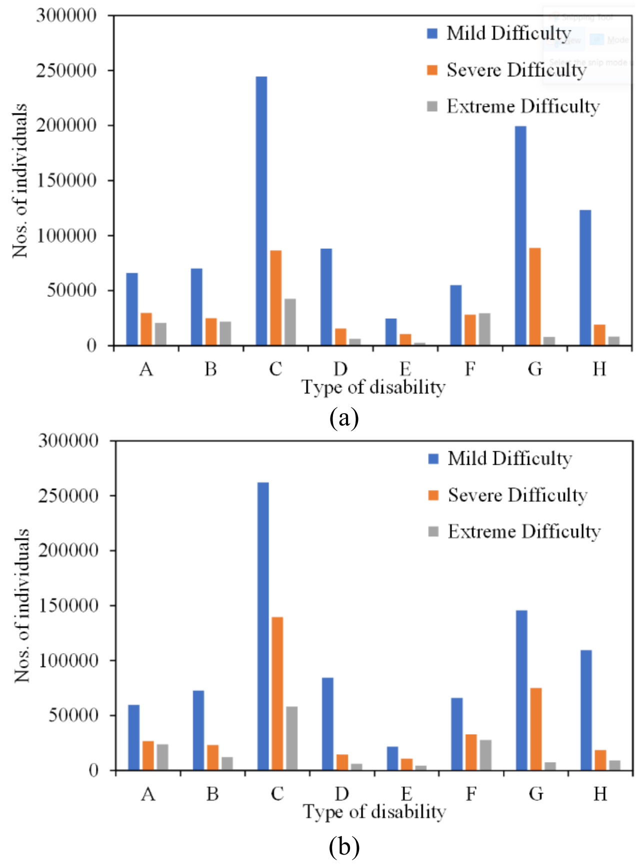


FIGURE 2. Saudi population with disability type and degree of difficulty for (a) Male (b) Female.

Most scholarly research has focused on analyzing the challenges faced by people with disabilities at specific intervals of a journey, including public transit. Jenkins et al. [13] and Rosenberg et al. [14] showed that the past research generally focused on the physical infrastructure, while

Soltani et al. [15] revealed that the primary focus of previous studies was the public transport system itself. It is crucial to emphasize that any obstacle in the built environment prevents disabled people from using public transit for the first time. While investigating the difficulties faced by disabled people in a complete public transport journey, some studies [16], [17], [18] either concentrated on a few types of disabilities or the elderly population, whose disabilities are a function of the natural aging process. Gallagher et al. [19] investigated the challenges faced by people with visual impairments, looking at both rural and urban settings, while Ahmad [16] focused on physical disabilities in a rural context.

A comprehensive analysis is essential to identify common and distinct accessibility barriers across various disability types, informing more inclusive urban design strategies. Nonetheless, few studies reported on the way out of this type of barrier, keeping in mind the case studies of various countries around the globe. In light of the discussion before, this review aims to look into the underlying factors contributing to the difficulties that independent travelers with disabilities encounter when utilizing the public transportation system. It also aims to identify key barriers and facilitators to public transportation for persons with disabilities.

Unlike previous systematic review that are mainly focused to address the specific aspect of disability-inclusive public transport system, such as policy frameworks, infrastructure accessibility, the current review undertakes a holistic approach encompassing diverse aspects Specifically, methods used to measure accessibility, followed by an in-depth analysis of key barriers; physical, communication, cognitive, attitudinal, and economic faced by disabled population in urban contexts. Furthermore, a critical overview of existing studies is also presented, ensuring their relevance and rigor, thereby strengthening the connection between past research and the current review's focus. The current review also highlighted the key contributions and distinctive features of prominent transportation systems to provide a comprehensive understanding of their role in addressing accessibility challenges. Lastly, a detailed comparison of disability-related challenges faced by this population group in developing and developed countries. Based on literature from diverse disciplines, this review highlights existing barriers and evolving solutions, finding a clear connection between prior research and the need for an all-inclusive public transportation framework.

This study deals with the state of the art in enhancing the accessibility of disabled persons. Figure 3 illustrates the flow of the detailed review process followed in this study, explaining the analyses and interpretation of the keywords, article type, and the research area's potential. The remaining paper is structured as Section II, which discusses the method used for the paper. Section III explained different methods of evaluating accessibility; Section IV summarized the barriers and challenges of using public transportation in past studies from various countries for disabled pedestrians. Section V describes the different case studies of public transport accessibility for disabled users, and Section VI discusses the disabled pedestrian satisfaction with public transport. The subsequent sections discuss key features and best practices for transportation systems and the final prospects and conclusions of the review.

II. REVIEW APPROACH

Understanding existing research is crucial for building knowledge and driving scientific progress. Literature reviews provide researchers with a snapshot of current insights on a specific topic and pave the way for future studies. We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Extension for Scoping Reviews to ensure transparency and minimize bias. This approach promotes rigor and reproducibility by setting clear criteria for selecting and categorizing relevant studies, ultimately reducing potential research bias.

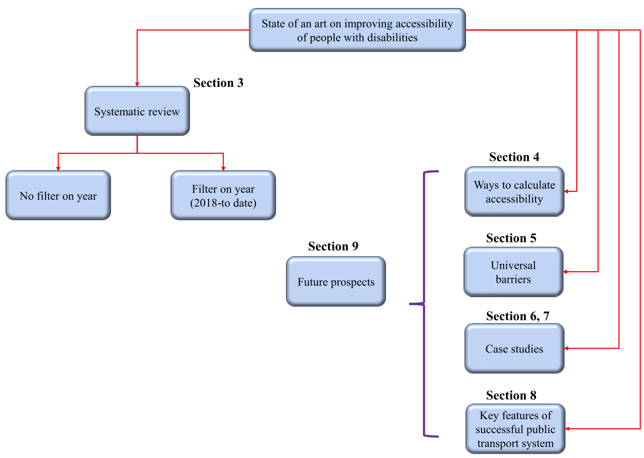


FIGURE 3. Layout of the current study on the state of the art in improving accessibility for people with disabilities.

A. SEARCH STRATEGY

Web of Science, Scopus, and PubMed databases were searched for relevant literature on disabled and public transport. The appropriate keywords were identified by initially searching the associated public transport systems and disabilities in Scopus-published data. The result revealed six clusters based on mutual association analyzed through VOS viewer (Figure 4). The analysis was based on association strength using a VOS viewer. Cluster 1 appeared to be the densest compared to the remaining clusters. Frequent use of "public transport", "disability", "transportation," "accessibility", "public policy", and "United States" reflects the importance of accessibility for disabled persons and public policy for normal societal conditions. The major work related to the issue has been reported in the United States. The remaining clusters encompass keywords associated with (2) medicine and the public transport system and disabilities, (3) health care delivery and public transport system and disabilities, (4) disability life and the public transport system and disabilities, (5) demographic studies and public transport system and disabilities and (6) rehabilitation and public transport system and disabilities. The final keywords selected were only limited to transport and disabilities, such as disability, public transport, traffic and transport, accessibility, transportation, patient transportation, disabled person review, traffic accident, public transportation, people with disabilities, urban transportation, transportation planning, wheelchairs, aged, public health, mobility, and middle-aged. The shortlisted keywords were linked using "OR" and "AND" to find the relevant literature on the topic. This Boolean strategy helped to narrow down results significantly and exclude irrelevant ones. Table 1 presents the details of the systematic review of related keywords.

Specifically, the search strings were constructed using a combination of keywords related to transport, disabilities, and accessibility. Within each of these categories, "OR" operator is used to combine synonymous terms. For example, a simplified version of one component of our search string would be:

("disability" OR "disabled" OR "handicap" OR "impairment")

These individual components were then combined using the "AND" operator with terms related to transportation and accessibility, for example:

("disability" OR "disabled" OR "handicap" OR "impairment") AND ("public transport" OR "public transportation" OR "mass transit") AND ("accessibility" OR "accessible")

To test the sensitivity of our search strings, an iterative approach was employed. Initially, we conducted broad searches using a limited number of key terms. We then examined the results to identify relevant articles not captured by our initial search. New keywords and phrases from these articles were then incorporated into our search strings, and the process was repeated. This iterative process continued until we observed minimal changes in the search results with the addition of new terms, indicating that the search strategy was sufficiently sensitive.

B. INCLUSION CRITERIA

The article inclusion criteria for selecting the articles retrieved from the keywords included the articles published between 2018-2024, resulting in limited publications overall. Compared to the earlier analysis based on using a VOS viewer encompassing the total number of studies, irrespective of publication year and vast search scope, there was no drastic effect on filtering the data. Most of the related work published after 2018 highlights a continuing effort in recent years to enhance the accessibility of disabled people to public transit. Simplified attention on particular keywords within a specified era offers a more conversant view of the current state of research at this crucial nexus between public transport and disability. Those articles focusing on disability and public transport were considered, while articles studying private transportation or individual mobility devices were not considered. Articles published only in English were considered for further screening. In addition, no additional screening was carried out for inaccessible articles.

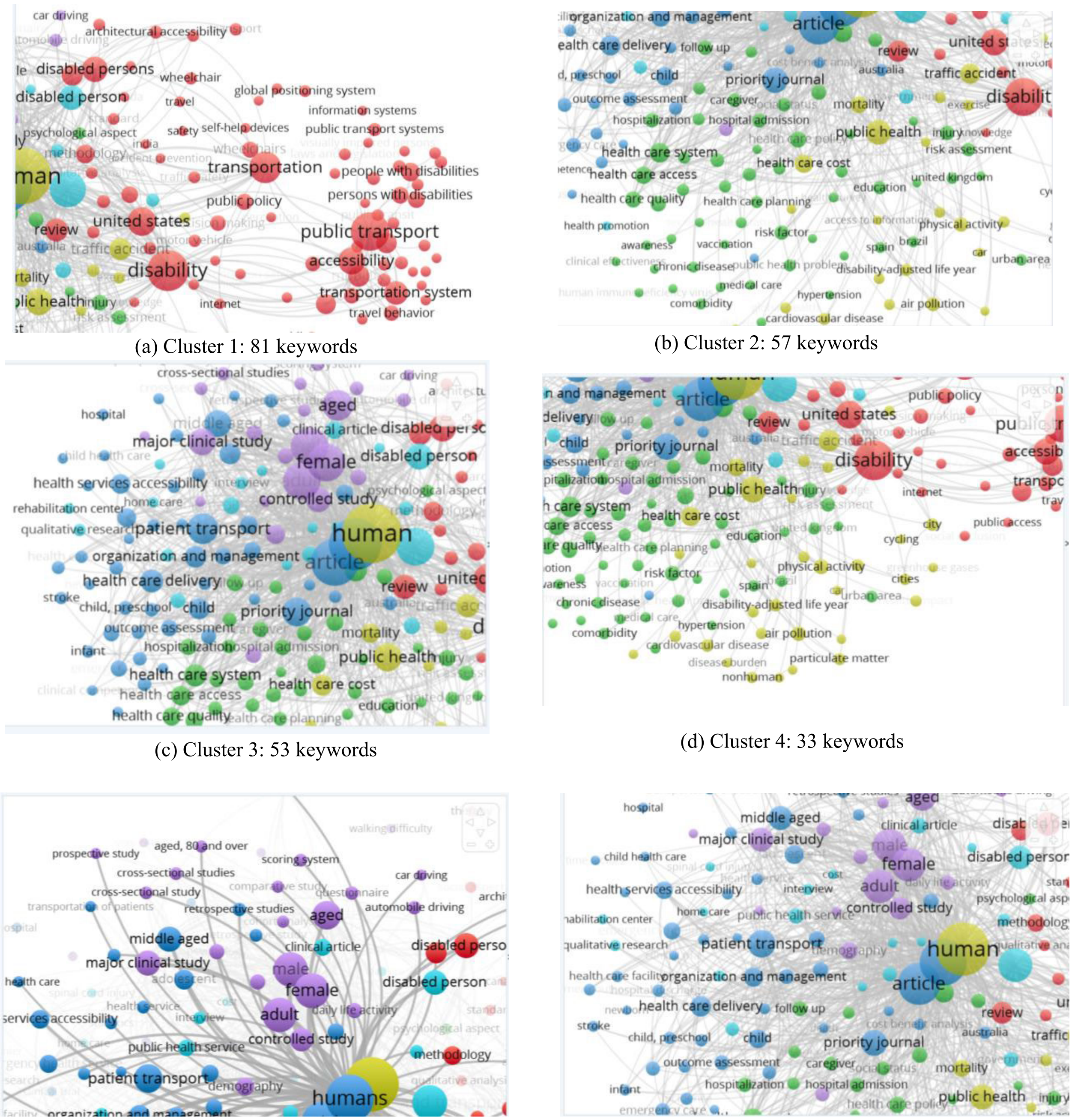
As mentioned earlier, Web of Science, Scopus, and PubMed were searched. These databases were selected due to their comprehensive coverage of transportation research, disability studies, and public health. The search strategy combined keywords related to "disability," "accessibility," "public transport," and "mobility". The Boolean operators (AND, OR) were used to refine the search. Articles published between 2018 and 2024 were included to capture the most recent research on the topic, to highlight the continuous effort in recent years to enhance the accessibility of disabled people to public transit. Articles were excluded if they were not in English, focused on private transportation or individual mobility devices, or inaccessible. After removing duplicates (n=221), titles and abstracts of the identified articles (n=1714) were screened for relevance based on the inclusion criteria. The full text of potentially relevant articles (n=235) was retrieved and assessed for eligibility. Articles were excluded at the full-text stage if they were secondary studies (n=5) or lacked relevance to the research question (n=195). A total of 35 studies met the inclusion criteria and were included in the review. A standardized data extraction form was developed to collect relevant information from the included studies.

III. ACCESSIBILITY ESTIMATION METHODS

Numerous researchers have evaluated how physical impairments can lead to social exclusion and affect the accessibility of an individual [17]. The following two approaches to measuring accessibility are prominent in scholarly literature.

A. ACCESSIBILITY OF OPPORTUNITIES

The first approach, termed' accessibility of opportunities,' evaluates the physical features of facilities such as healthcare centers, fitness facilities, and recreational spaces [20], [21], [22]. This method assesses the ease of access within these buildings and navigates essential amenities like restrooms, dining, parking, etc. It involves a comprehensive analysis of whether these facilities meet established accessibility standards, ensuring that individuals can utilize the space effectively, regardless of their physical abilities. This technique often focuses on 'absolute accessibility,' establishing if a facility is accessible broadly without considering any disparities that may occur between various groups, such as the visually impaired or physically impaired. For example, even while a building satisfies the minimum standards for accessibility, this evaluation could not consider the diverse requirements of individuals with various impairments or the exacerbated obstacles encountered by members of disadvantaged populations. Thus, while the 'accessibility of opportunities' approach is critical in establishing a baseline of accessibility, it may ignore the subtle problems and inequalities that particular populations face in adequately utilizing these opportunities.



(a) Cluster 1: 81 keywords

(b) Cluster 2: 57 keywords

(c) Cluster 3: 53 keywords

(d) Cluster 4: 33 keywords

(e) Cluster 5: 28 keywords

(f) Cluster 6: 21 keywords

FIGURE 4. Analysis of keywords associated with the public transport system and disabilities.

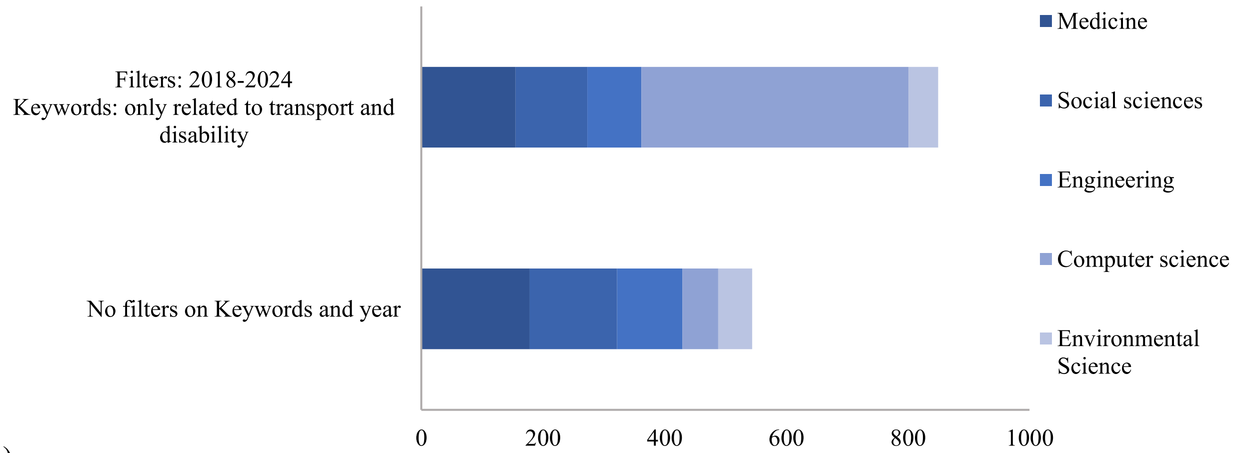
B. ACCESSIBILITY TO OPPORTUNITIES

The second approach, 'accessibility to opportunities,' examines public spaces concerning individual physical abilities. This line of research, though less frequent, often focuses on the accessibility challenges faced by wheelchair users. Studies in this domain commonly highlight significant accessibility gaps between disabled and non-disabled individuals. These disparities are measured in two ways: firstly, by assessing the pedestrian network, focusing on distance-based and connectivity aspects, and secondly, by integrating this network analysis with the locations of urban amenities to measure opportunity-based accessibility disparities.

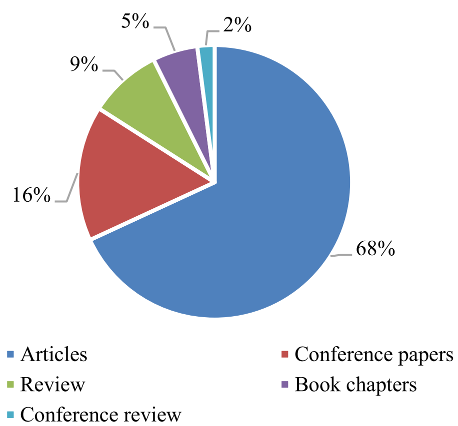
Research focusing on distance-based disparities emphasizes how the physical environment affects accessibility for disabled individuals compared to their non-disabled counterparts. This involves calculating the distances from a starting point to various destinations, highlighting that physical disabilities can increase the distance and complexity

TABLE 1. Details of the systematic review of related keywords.

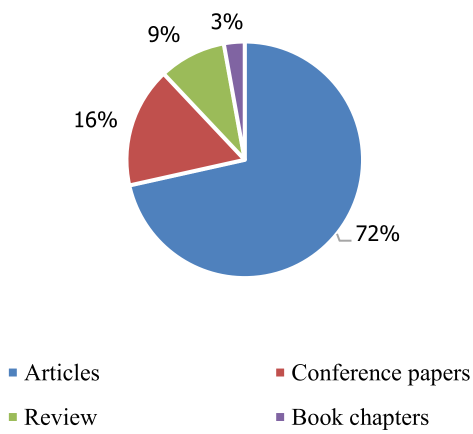
Main keywords	Filter	Number of articles on the subject area	Number of articles on document Type	Open Access Articles
Public transport system, disabilities	No filter on keywords and year	Medicine = 178; Social Science = 144; Engineering = 107 Computer Science = 59; Environmental science = 56; among others.	Articles= 269; Conference Papers= 63; Review= 34; Book Chapter =21; Conference Review= 8; and others	174
Public transport system, disabilities	Filters: Year 2018-2024 Keywords: only related to transport and disability; terms related to medicine were excluded	Medicine= 155; Social Science= 118; Engineering=89 Computer Science=439; Environmental science = 49; among others.	Articles= 226; Conference Papers= 52; Review= 29; Book Chapter =9; and others	147



(a)



(b)



(c)

FIGURE 5. Details of a systematic review with primary keywords Public transport system and disabilities, a) number of articles published in various subject areas, b) document types using no filters on keywords and year (total open access articles = 174), c) number of articles published using filters: Year (2018-2024) and keywords only related to transport and disability (total open access articles = 147).

of travel routes [23], [24]. Another group of studies measures accessibility disparity based on the count of accessible opportunities for disabled individuals versus non-disabled ones. This approach sets a maximum acceptable travel time or distance, which is crucial in determining the extent of accessible opportunities. Various studies have employed this methodology, compared different demographic groups and revealed significant disparities in accessibility experiences,

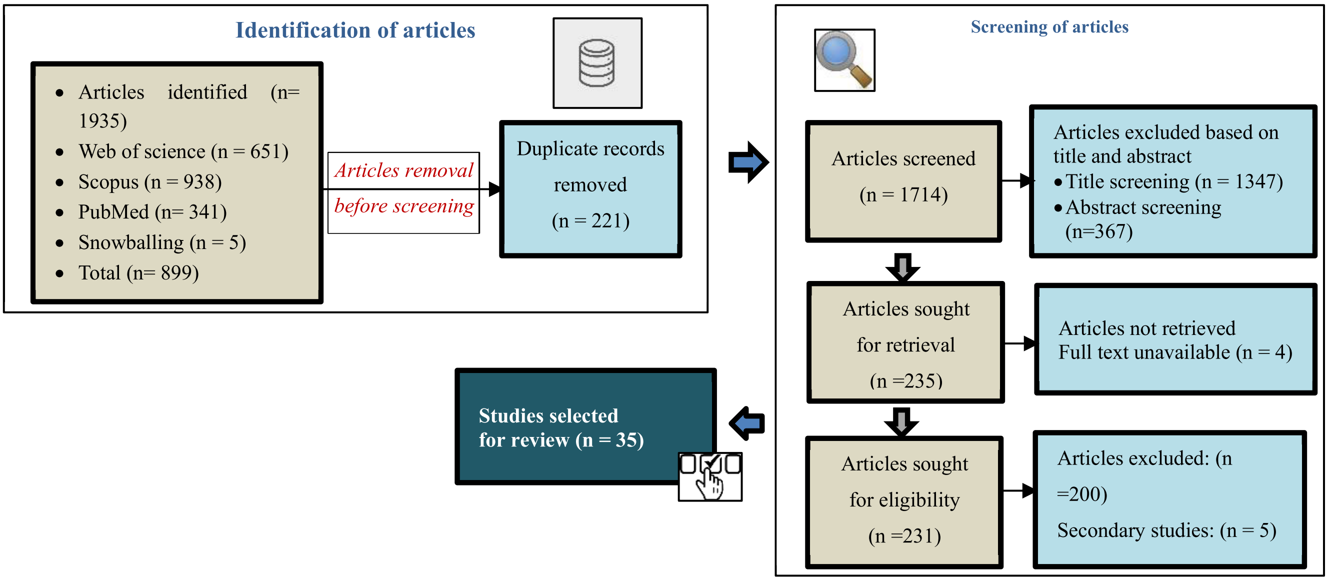


FIGURE 6. Identification, screening, and selection process of articles using databases.

particularly among those with disabilities [25], [26], [27].

IV. BARRIERS AND CHALLENGES FOR DISABLED USERS OF PUBLIC TRANSPORT

The transportation of people with disabilities for potential opportunities such as jobs, health facilities, educational institutions, retail outlets, and other utilities within a given time threshold is the most critical aspect of the transportation system, termed accessibility [28]. The term "universal barriers" refers to barriers and difficulties that make it difficult for people with disabilities to utilize public transportation systems effectively and comfortably when they desire to access these opportunities. The physical infrastructure, information dissemination, other passengers' and transportation employees' attitudes, and other components of the transportation experience can all be considered barriers. The entire journey chain of the public transport system encompasses two broad categories of services, namely "built environment" and "public transport" [29]. Every journey starts with available information, especially for those with disabilities who need to make sure the entire trip is accessible before they leave. Inadequate information may frequently lead disabled people to trouble adjusting to unforeseen challenges. With adequate information, DP can make informed decisions, such as whether to take public transportation or look into other options for mobility. Overall, the obstacles include commonly considered inaccessible infrastructure, information and communication barriers, attitudinal barriers, economic barriers, safety and security concerns, and safety and security concerns. The impact of these barriers is even more pronounced in developing countries, where public transport infrastructure is often underdeveloped, and alternative travel options are limited. In such regions, inaccessible pedestrian infrastructure, a lack of affordable transport options, and limited awareness further restrict mobility for disabled individuals. Figure 8 illustrates the critical barriers in the public transport system for people with disabilities.

A. PHYSICAL BARRIERS

Significant obstacles may arise from physical barriers in transportation infrastructure, including buses, trains, and subway stations. These obstacles could be a lack of ramps or lifts, small aisles, and insufficient room for those in wheelchairs or who have other mobility issues. These types of barriers are mainly related to the "Built Environment." The built environment significantly impacts how easily people with impairments can travel. The difficulties associated with accessibility in public transport start as soon as the user leaves their home, making it difficult to utilize this mode. For example, poorly maintained pathways, frequently characterized by uneven surfaces and fissures, are identified as a common problem [13], [14]. Poor curb ramps make it more difficult for people with physical disabilities to use wheelchairs or walkers, and they put people with sight impairments at risk when crossing highways [30], [31]. Inadequate lighting makes it difficult for persons with limited vision to see signs and conceal possible trip hazards [14], [16]. Accessibility is also impacted by other barriers, such as background noise, the absence of audio announcements, and crossings on busy roadways [13], [32]. In situations with no practical alternatives, construction-related problems, such as improper signage placement or complete obstruction of walkways, may compel travelers to turn around [33].

Previous researchers also mentioned that long distances to stops, additional routes towards terminals, poor lighting, safety, and shelter are some of the obstacles to accessible public transport [16], [34]. Physical restrictions are a significant hurdle while getting on and off buses, especially those with steps [35]. For those with physical disabilities, platform gaps and uneven access provide difficulties [15], [36]. The lack of appropriate timetables and audio announcements is one of the main sources of confusion for visually impaired passengers. Bus layout changes can make it difficult to find a seat, and visually impaired travelers rely on drivers to make stop announcements when audio announcements are unavailable. For this reason, priority seat placement near the driver and door is essential [19].

B. COMMUNICATION BARRIERS

Infrastructure changes made to improve accessibility for people with physical impairments might not always address issues faced by people with communication disabilities. Since communication is a reciprocal connection, people with communication challenges come in many forms. These people may have developmental or acquired disabilities or a combination of physical, sensory, speech, language, or cognitive impairments [37]. Many studies demonstrate the importance of improving communication access when using public transit for people with communication challenges. It was fourth in Canada's priorities list, including government, healthcare, and disability services [38]. A study conducted in Hong Kong also highlighted communication in public transit as one of the top five significant environmental barriers identified by participants with moderate to severe speech impairment (dysarthria) [39]. Challenges include negative attitudes from communication partners, lack of contextual information, time limits when using services, and limited availability of communication tools for efficient expression [38], [39], [40]. Inadequate or difficult-to-find information on public transportation timetables, routes, and accessibility features certainly affects disabled people [41], [42]. Insufficient information includes the lack of up-to-date material offered in accessible formats (such as audio or Braille) or digital platforms inaccessible to those with cognitive or visual impairments.

C. LACK OF COGNITIVE ABILITY

According to a study conducted in North Dakota, older women with reduced cognitive ability made fewer trips and had trouble using public transit [43]. Cognitive difficulties were noted by Fischer and Sullivan [44] because users have to interpret a variety of navigation artifacts, like schedules and maps. Cognitive impairments impair orientation, memory, and problem-solving skills, which makes it difficult to follow directions, find the right car, and comprehend announcements. Four categories of individuals with cognitive functional limits were found by [45]. They listed psychological adaptation, external guidance, fear of complicated activities, and worries about upsetting others as reasons for quitting transit use. The study identified differences among people with lifelong cognitive disorders and stressed the significance of the entire journey. Wasfi and Levinson [46] examined the physical and mental obstacles adults with developmental impairments face when using public transportation. These issues included trouble standing, reading schedules, and comprehending announcements. These results highlight the various requirements and experiences that people with cognitive impairments have when utilising public transportation.

D. ATTITUDINAL BARRIERS

For people with disabilities, unwelcoming behaviors and attitudes from other passengers and transportation employees, such as discrimination [47], a lack of support [48], or a lack of awareness [49] of the needs of individuals with disabilities, can lead to uncomfortable experiences.

E. ECONOMIC BARRIERS

Public transport accessibility for people with disabilities may be restricted by high costs [50] for accessible options or by a lack of subsidies. Concerns about security and insufficient safety precautions may discourage people with impairments from utilizing public transit. This includes poorly illuminated stations [51], inaccessible emergency exits, and apprehension about theft [52] or harassment [53].

V. PUBLIC TRANSIT ACCESSIBILITY CASE STUDIES

After identifying key barriers to public transport through a systematic literature review, we selected case studies that showcase best practices in making public transport more inclusive. Our selection included examples from both developed and developing countries to provide a balanced and comprehensive perspective on effective strategies.

Universal design is crucial to ensure equal access and usability of public services for all individuals, regardless of impairments. The universal design concept aims to promote equal access and usability of public services for all individuals, irrespective of impairments, within a specific area, ensuring uniform service quality [54], [55]. This can be done by promoting the reduction of barriers such as staircases, heavy doors, steep inclines, and insufficient signs or illumination [56]. Despite the efforts made by public institutions and advocacy groups, numerous affluent nations still have public transit systems that do not fully adhere to universal design principles. The infrastructure, encompassing transport systems, often caters to young, physically capable users, neglecting the needs of an aging population increasingly facing disabilities [57]. In 2012, about 14% of Canadians had a physical handicap [58]. The absence of universal design can be as constraining to individuals with physical disabilities, impeding their ability to access the same possibilities as those without such constraints [54], [59].

City governments worldwide have developed initiatives to promote disability-inclusive public transport initiatives. For example, the Toronto Transit Commission (TTC) prioritizes wheelchair accessibility by providing universally accessible vehicles and equipping 35 out of 69 subway stations for customers with physical disabilities as of 2017. The TTC aims to make all stations accessible by 2025. Approximately 5% of the TTC's capital budget is designated towards enhancing accessibility. In addition, the GO Transit system provides regional public transportation in the Greater Toronto Area (GTA) and Hamilton Area, with most commuter train stations and bus routes equipped with wheelchair accessibility. In contrast, The Société de Transport de Montréal (STM) buses can accommodate wheelchairs; however, only 12 of 68 subway stations had lifts during the investigation. Also, The Agence Métropolitaine de Transport (AMT) oversees commuter train services with 66 stations, of which only ten can accommodate wheelchair users.

Figure 7 shows the accessibility of work for those using wheelchairs in Toronto and Montreal. Toronto demonstrates better wheelchair accessibility to jobs compared to Montreal, with nearly 50% of census tracts (CTs) having an accessibility ratio of over 80%, and 80% of CTs exceeding 60%. In contrast, Montreal faces significant challenges, with only 2% of CTs reaching an 80% ratio and over 50% falling below 40%. Regarding socially vulnerable areas, Toronto shows more favorable conditions, while Montreal has fewer vulnerable CTs, but none exceed an 80% ratio. Neither city achieves 100% accessibility in any CT, indicating a universal need for improvement. Enhancements are necessary across all public transport accessibility levels to ensure equitable job access for wheelchair users and non-users alike.

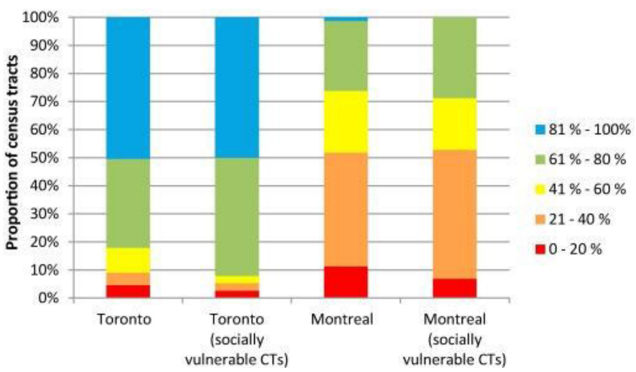


FIGURE 7. Percentage of census tracts in the City of Toronto and the Island of Montreal, including all census tracts and those recognized as socially vulnerable, categorized by different ranges of accessibility ratios (Adopted from [60]).

Similarly, another study evaluated the accessibility of Ahmedabad's public transport system for people with impairments. With an average accessibility score of just 30.33%, the results showed that Ahmedabad's building accessibility was generally relatively poor, indicating significant barriers for individuals with disabilities. The accessibility of healthcare facilities, i.e., hospitals and clinical departments, was notably higher than that of other public infrastructure and transportation facilities [61]. The case study's findings suggest an urgent need for extensive renovations and adaptations to Ahmedabad's public infrastructure and transportation network to foster greater independence and full participation for people with disabilities in urban life. In one study, one hundred and fifty wheelchair users were interviewed to provide their experience after a decade of implementing the Disability Discrimination Act in the UK. Wheelchair users still face significant challenges in navigating city centers, with 61% reporting that urban planning and design contribute to their disability experience [56]. While modern, enclosed shopping centers are generally accessible (80% of wheelchair users find them easy to navigate), traditional shopping streets with vehicle traffic and market areas remain problematic for at least one-third of wheelchair users. Another study examined the difficulties faced by people with communication disabilities while using Victoria's rail system.

One study explored the experiences of individuals with communication disabilities on a rail network in Victoria, Australia, aiming to identify the barriers they faced [37]. The study highlighted primary challenges for passengers with communication disabilities: inconsistent access to information, difficulties navigating a complex service system, and uncertainties surrounding help-seeking and receiving assistance. Despite encountering numerous challenges, most participants had never lodged formal complaints; however, they provided valuable suggestions for service improvements, including enhanced staff training, increased use of communication tools, and simplified information delivery. Another study examines wheelchair accessibility in Istanbul's central business district, revealing significant user challenges in Turkey's most urbanized city. The study assessed 26 public buildings using an adapted questionnaire and uncovered a stark contrast in accessibility features. Public transportation emerged as the most problematic area, with a mere 25% compliance rate to accessibility guidelines, highlighting a critical gap in inclusive urban design. Conversely, building entrances showed the highest compliance at 79%, suggesting some progress in architectural accessibility. The study also noted a positive trend towards improved accessibility in newer constructions, indicating a growing awareness of inclusive design principles. However, the findings underscore a crucial disconnect between existing legislation and practical implementation, particularly in the absence of robust regulations. Recently Hermawan, S., & Anggoro, O. F. T [62] reported significant accessibility issues within Indonesia's public transportation system. Simanjuntak [63] notes that the Trans Metro Bandung bus service lacks accessible facilities, presenting a barrier for PWDs. Similarly, Wahyuni et al. [64] found that the Batik Solo Trans bus service has inadequate facilities, causing access difficulties for PWDs. Furthermore, Aryanti et al. [65] highlight that commuter rail stations in Indonesia have infrastructure deemed "inaccessible" to PWDs, indicating a systemic challenge in providing equitable transportation options.

VI. DISABLES USERS' SATISFACTION WITH PUBLIC TRANSPORTATION

Accessibility in public transportation is a crucial factor affecting the quality of life for people with disabilities. Various studies have examined the experiences and satisfaction levels of disabled individuals using public transport systems

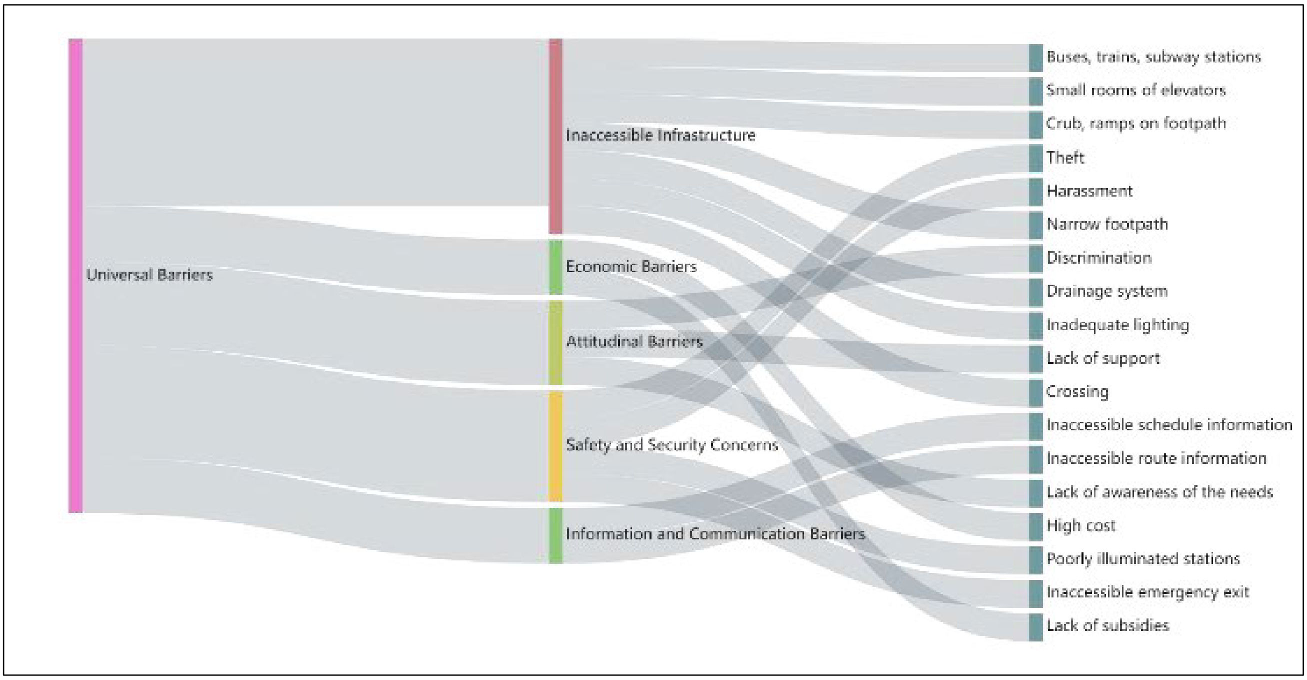


FIGURE 8. Key barriers in a typical journey by public transport users with disabilities.

TABLE 2. Key contributions of the case studies investigated in this study.

Case Study Area	Key Contributions and Findings	Reference
Montreal and Toronto, Canada	This study developed a methodology to assess and compare public transport accessibility for wheelchair users versus non-wheelchair users in Montreal and Toronto, revealing significant disparities in job accessibility. The findings show that wheelchair users in Toronto access 75% of the jobs available to non-wheelchair users, while in Montreal, they access only 46%, emphasizing the need for universal access in public transport planning.	[60]
Istanbul, Turkey	This study aims to evaluate how well public buildings in Istanbul's central business districts comply with wheelchair accessibility standards. Twenty-six public buildings were considered. The architecture of wheelchairs was also assessed, which showed that the main barrier stopping wheelchair users from visiting public facilities is public transit.	[54]
Ahmedabad, India	The study aimed to evaluate the accessibility of Ahmedabad's public transport system for people with impairments. With an average accessibility grade of just 30.33%, the results showed that Ahmedabad's building accessibility was generally relatively poor. The accessibility of hospitals and clinical departments was notably higher than that of other public infrastructure and transportation facilities.	[61]
British city of Swansea, UK	One hundred fifty people who use wheelchairs were interviewed in-depth to provide the information. Ten years after the UK's Disability Discrimination Act of 1995 went into effect, these interviews aimed to investigate and reassess the accessibility situation in city centers. Sixty-one percent of wheelchair users, for example, stated that they believe that places' layout and design contribute to their handicap.	[56]
Victoria, Australia	This study examined the difficulties people with communication disabilities face when using Victoria's rail system. It highlighted problems with information accessibility, service complexity, and the culture of asking for assistance. Diverse communication techniques are advised, and employees with adaptable problem-solving skills are trained.	[37]

across different regions. Table 3 summarizes the literature related to the experiences of disabled people with various disability issues. Mwaka [66] comprehensively investigated the satisfaction level of people with disabilities. Almada and Renner [67] evaluated the ergonomics and accessibility issues in public transportation for people with disabilities who used wheelchairs and others with mobility impairments in Bresil. the study was focused on bus services in the public transport system. A questionnaire assessed the satisfaction levels from 0 (not satisfied) to 15 (satisfied). The key areas were evaluated, including the schedule, employee training, guidance, waiting times, the distance to the bus stop, and the feeling of a disabled person being a burden on others. The 'schedule' scored 5.36, indicating moderate dissatisfaction. The employee training and guidance in connection to assisting impaired people received a slightly higher score of 6.24, suggesting room for improvement. Waiting times were a substantial concern, with standard passenger waiting time scoring 5.41, and the wheelchair users' waiting times secured a slightly better score of 6.06. The distance to the bus stop revealed moderate dissatisfaction, scoring 5.25. The feeling of being a 'burden to others' scored 5.84.

Apart from the factors mentioned above, the accessibility features within the bus were also assessed, which showed varied satisfaction levels. The ramp scored 6.40, while the bus's interior and platform space were rated at 7.01 and 6.06, respectively. The maneuvering area within the bus obtained a score of 6.28, and the placement of wheelchair users inside the vehicle earned a score of 6.57. Bezyak et al. [68] studied the barriers preventing the general public and people with disabilities from using public transportation. One thousand seven hundred forty-eight samples, 49% of male respondents from 50 states of the US, were considered in the survey. 65.5% of the respondents highlighted various obstacles that prevent them from using public transportation. Most interestingly, 47.6% of disabled persons reported unequal access to public transit in comparison to others in their community. In a similar study, Bezyak et al. [50] assessed the key barriers and their weight experienced by people with disabilities. The main concerns were the drivers not calling out the stops and inappropriate attitudes of drivers, accounting for 30.2 and 26.7%, respectively, among the total number of data samples. Bigby et al. [37] investigated people with communication disabilities and their experience with the barriers in the train service. They found that disabled persons without cognitive or visual impairments were accessible to train.

Designing a disability inclusive public transportation system warrants effective stakeholder involvement and engagement. Including the feedback from a disabled population can effectively highlight the barriers and unique challenges this group faces (such as poor route connectivity, inadequate accessibility features, and inconsistent service quality). Identification of such barriers can help to overcome these challenges with contemporary solutions. Further, involvement of policymakers and urban planners is vital for universal design principles, regulatory enforcement, and participatory planning to improve accessibility for disabled individuals. Inclusion of such perspectives, public transit can effectively foster inclusivity and address diverse mobility needs for disabled individuals.

In contrast, the deaf and hard-of-hearing persons could not access visual announcements. The noise at the station also creates hurdles in understanding disabled persons using hearing devices by the staff. Carlsson [17] studied disabled persons with physical, visual, and auditory problems to identify the issues with using public transportation from a travel chain perspective. The details of the barriers are given in Table 4 from the travel chain's viewpoint. Casey [69] studies the experiences of people with sight problems. The study was conducted on 13 samples of focus group discussions.

The significant barriers, for instance, difficulties in identifying and stopping buses due to sight loss and difficulties in accessing accurate and accessible pre-travel information, were evaluated. Frost et al. [71] investigated the feedback of wheelchair users while using ramps of transit buses to access public transportation. The percentage contribution of factors, including steep ramp slope, ramp width, and edge barriers, among others, was investigated. A few other researchers reported a similar nature of the studies [70], [79], [80].

VII. KEY FEATURES FOR DISABLED INCLUSIVE PUBLIC TRANSPORTATION

Universal design principles in public transportation are essential for ensuring accessibility for all users, particularly those with disabilities. A comprehensive approach to implementing these principles can significantly improve the mobility and independence of disabled individuals. An exemplary case study of London's transportation system illustrates key facilitators for successful public transport accessibility. The approach of Transport for All (TFL) in addressing diverse accessibility needs across various modes of public transportation. In London and the rest of the UK, 11 percent of adults have mobility difficulties, of which 5% use special equipment like wheelchairs to be mobile [81]. A person is classified as having a "disability" under the Equality Act 2010 if they have a physical or mental impairment that significantly and permanently limits their capacity to engage in regular day-to-day activities [82]. Considering these statistics, Table 4 is presented to extract the key features of the London transportation system, i.e., TFL.

TFL gives accessibility for people with impairments through many essential elements. The bus network provides extra amenities like next-stop audio and visual systems and daily ramp assessments to guarantee handicapped accessibility. Under the Freedom Pass program, most of TFL is free for people with disabilities and those 60 years of age or older. With continual attempts to modernize stations and add features like wide-aisle gates, tube and train stations have come a long way toward becoming step-free. There are 22,000 taxis available, and organizations like Taxi Card offer subsidized transportation for people with severe mobility impairments.

In 2011–12, the Dial-a-Ride service, a door–to–door option for elderly and disabled passengers, recorded an impressive 1.4 million trips. Introduced in 2012, the Travel Support Card facilitates communication for people with disabilities, especially those who are cognitively impaired. Eight piers provide step-free access through river services, and pedestrian amenities include Pedestrian Countdown systems, tactile elements, and aural alerts. A legible wayfinding system facilitates pedestrian travel with approximately 1,100 signs across 25 boroughs. Appropriate seating in public transport and waiting areas prioritizes individuals with limited standing capacity. At the same time, extra customer information, such as step-free maps, online resources, and the Journey Planner application, improves the experience even more for people with disabilities and demonstrates persistent dedication to accessibility and ongoing development in the London public transport field. Public transportation stations should also offer amenities like ticket vending points, entry gates, communication devices, rest areas, and sanitary facilities that ensure equitable access and usability for all passengers, regardless of their physical abilities or limitations.

Evcil [54] studied the architectural obstacles encountered by individuals using wheelchairs in public structures in

TABLE 3. Summaries of research dealing with the satisfaction level of disabled persons while using public transportation.

Place	Size of sample	Type of Disability	Mode of public transport	Objective	Reference
Novo Hamburgo, Bresil	30	Physical	Bus	Evaluating the ergonomic and accessibility challenges encountered by wheelchair users and individuals with mobility impairments	[67]
United States of America	1748	Speech/communication, Auditory, chronic health conditions, intellectual, visual, cognitive, psychiatric, and physical.	Paratransit, personal vehicle, commuter/light rail, bus, taxi, bicycle, walk, Uber or Lyft.	Assessing the barriers preventing people with disabilities from public transportation	[68]
New York, USA	4161	Speech/communication, Auditory, chronic health conditions, intellectual, visual, cognitive, psychiatric, and physical.	Subway, paratransit, bus, taxi, light train.	Comprehensive description of barriers to using public transport and paratransit by people with disabilities	[50]
Victoria, Australia	21	People with communication disabilities	Train	Evaluating the viewpoint of disabled people having communication problems about the barriers in accessibility	[37]
Helsingborg and Kristianstad, Sweden	20	Auditory, physical, visual,	Bus	To examine the issues within using public transportation from a travel chain perspective.	[17]
Dublin, Ireland	13 (focused group discussion)	Visual	Bus, train	Experiences of people with vision disabilities and using public transportation	[69]
Istanbul, Turkey	12	Visual and physical	Metro	To investigate the methods employed for barrier-free design and the degree of accessibility present at metro stations in Turkey	[70]
Louisville, USA	384	Physical	Bus	The feedback of wheelchair users while using the ramp of transit buses to access public transportation	[71]
Mumbai India	12	Auditory/Deaf	Suburban trains	Studying the right to occupy space on suburban trains for persons	[72]
L'Aquila Itlay	5	Visual	Pilot study/Bus	Analyzing low cost public transportation for peoples with visual disabilities	
Dalarna and Örebro, Sweden	2758	Auditory, physical, visual, Severe allergies	Train	Exploring the need of pre-travel information among public transit riders with varying functional disabilities	[73]
Guayaquil city Ecuador	10	physical and sensory	Metrobus	Proposing an inclusive public transit framework considering the needs of disabled peoples	[74]
Rural contexts across 16 states in USA	33	Mobility, cognitive, auditory, visual	Bus, train	Exploring the mobility patterns of disabled people in rural context with lack of public transit services	[75]
Auckland, Wellington, Christchurch New Zealand	165	Physical, visual, cognitive, multiple	buses, trains, and ferries.	Understanding the needs of disabled population using public transit involving transfers	[76]
Edinburgh UK	23	Visual and speech	Urban bus	Investigating the factors to encourage the use of public transit among people with disabilities	[77]
Tunja, Colombia	17	Visual	Bus	Understanding the needs of access system for visually impaired peoples to use public transit	[78]

Turkey, which possesses disability legislation but lacks explicit restrictions. Istanbul is a highly populated city and resembles other metropolises in emerging economies. The study employs a questionnaire partitioned into nine discrete components. The first section (A) compiles fundamental descriptive data about the buildings, encompassing their names, purposes, positions, and construction dates. The subsequent sections (B to I) assess different facets of public structures. The factors encompassed were the accessibility of public transport to 26 buildings, building entrance, building access, vertical and horizontal movement within buildings, and the accessibility of toilets, public phones, and parking areas. Each section evaluates distinct issues separately to offer a complete perspective. Each questionnaire

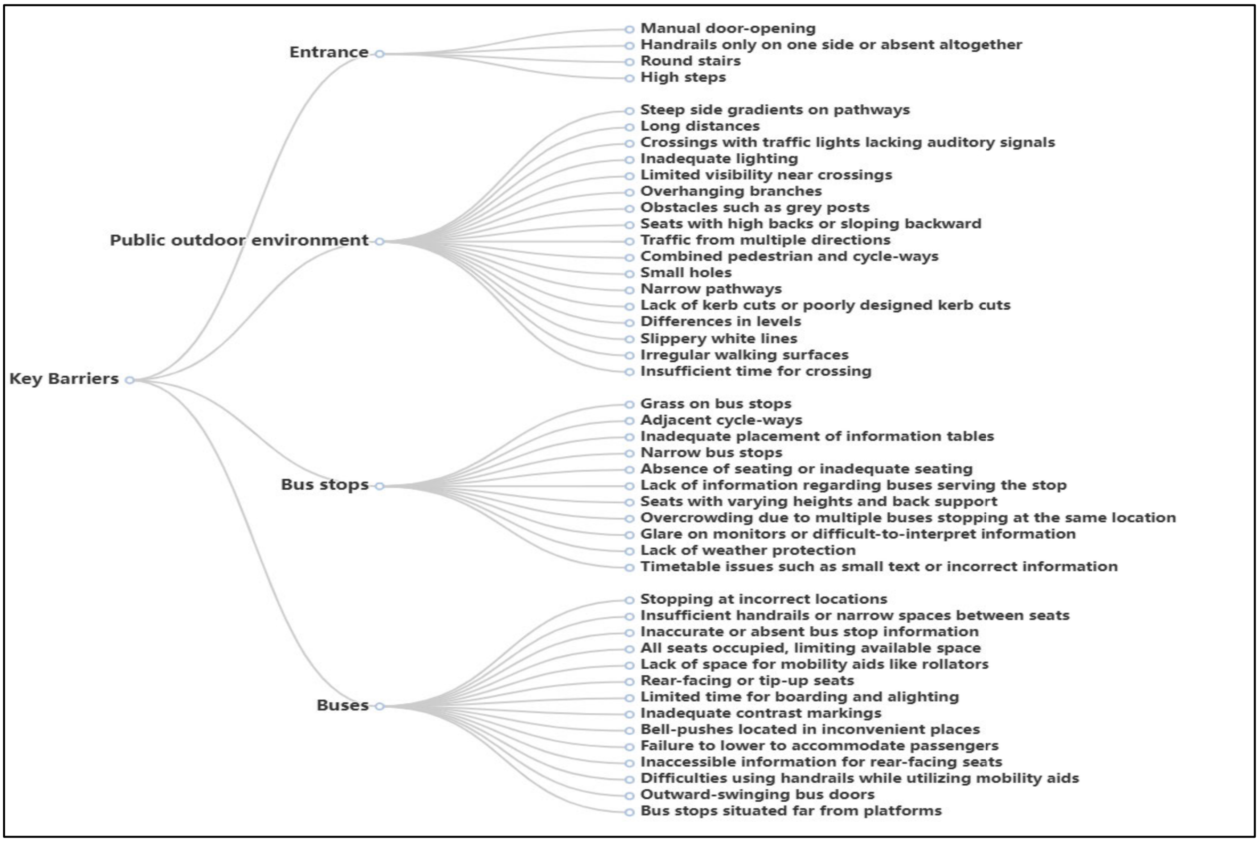


FIGURE 9. Key barriers for people with disabilities in travel chain perspectives.

item assessed the compliance of buildings as complying (score=1), non-compliant (score=0), or partially compliant (score=0.5).

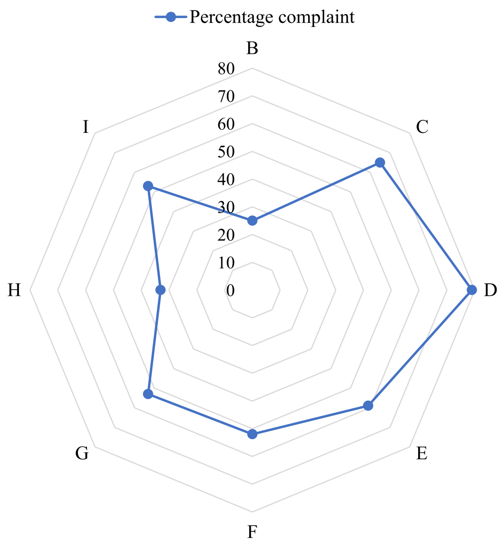


FIGURE 10. Radar plot of the compliance score of Istanbul city in each section.

A few other case studies have also been reported. Varma et al. [61] evaluated the accessibility of Ahmedabad in India and found that the average accessibility grade was 33.3%. Bromley et al. [56] investigated the British city of Swansea, UK, whereas Bigby et al. [37] assessed the situation of Victoria, Australia, whose details are given in Table 4.

VIII. KEY CHALLENGES AND CONTEMPORARY SOLUTIONS

Artificial Intelligence (AI) has been widely used in various problems associated with public transport systems [83], [84], [85]. The use of AI in assessing accessibility in cities is growing [86]. Remote sensing methods such as Light Detection and Ranging (LiDAR) can take accurate 3D images of sidewalks and pedestrian pathways [87]. The technique can easily be used in smartphones to capture the surface, dimensions, and other information of pedestrian pathways, sidewalks, curb cuts, steep grades, and accessibility of bus stops, among others. The collected data can be processed with the help of an AI algorithm, and compliance with the relevant standard can be evaluated. DeepWalk is a prominent tool that can use similar techniques to generate detailed reports, data, and even 3D visualization [88]. Policymakers can use the generated reports to improve the built environment and make it friendly and accessible for all, especially people with disabilities.

Streetscape imagery via street-level photography, 360° panoramic view, or drones can be used to capture photographs of building fronts, sidewalks, public spaces, roadways,

TABLE 4. Key features of the transportation system for enhancing the accessibility of disabled pedestrians.

Key Features	Implementation Approach
Bus network accessibility	The bus should have a ramp for wheelchair users, and its operation is checked daily. Accessible stops, real-time arrival information, and next-stop audio and visual technologies improve the bus experience.
Location and spacing of bus stops	Bus stops should be within 400 meters of amenities to ensure accessibility for people with disabilities.
Shelters and benches	Shelters and benches at bus stops enhance comfort and accessibility.
Bus stop layout	Bus stops should provide sufficient space for passengers to wait and board without obstructing pedestrians. A clear area extending 2400mm from the curb should accommodate a wheelchair ramp.
Freedom pass	On most transport networks, disabled people and those 60 or older can ride for free.
Tube and Rail	Taxis should have features for various disabilities, making them 100% wheelchair-accessible. For residents of London with severe mobility impairments, taxi cards provide subsidized transportation, which permits travel in authorized taxis.
Dial-a-Ride	a free door-to-door service for older and disabled people can increase access to public transport.
Travel support card	Travel cards facilitate communication between individuals with impairments and staff, especially those with cognitive disabilities.
River services	In cities with canals, riverboats should be accessible.
Pedestrian facilities	Pedestrian countdown systems for safer crossings, tactile features, and aural alerts are examples of improvements to pedestrian facilities.
Customer information	Step-free maps, online tools, and instructions facilitate the use of many modes of transportation by people with disabilities. Users can access route information using the Journey Planner tool, and the network is guided by on-system signage.
Appropriate seating	Public transport should have seating accommodations in waiting areas and platforms to prioritize individuals with limited standing capacity.
Amenities at the public transport stations	Public transportation infrastructure elements such as ticket vending points, entry gates, communication devices, rest areas, and sanitary facilities should ensure equitable access and usability for all passengers, regardless of their physical abilities or limitations.
Bus entrance	Bus entrances should be designed with accessible steps, handrails, and grab handles to help remove barriers for users with disabilities.
Wheelchair space in public transport vehicles	The public transport vehicle should accommodate wheelchair users who can board without leaving their chairs.

buildings fronts, street furniture, public spaces, and other elements in urban and suburban environments [89]. Street-level imagery includes photography with a camera mounted on a vehicle or via someone. The imagery can also be used to identify the barriers by pedestrians or wheelchair users while accessing public transport. Advanced machine learning (ML) algorithms can automatically detect the barriers from the images that can hinder the accessibility of people with disabilities to the general public. Weld et al. [90] applied a deep learning algorithm to assess the infrastructure accessibility from streetscape panoramas from the image-based sidewalks. Hara et al. used Google Street View (GSV) images to improve the accessibility of blind riders by crowd-sourcing bus stop landmark locations [89]. The images obtained from the above sources have also been previously employed by CitySurfaces, an AI-based tool for understanding the visual world. The technique can automatically identify hazardous materials, such as cobblestones, uneven surfaces, steep slopes, and curb cuts, posing accessibility issues for wheelchair users [91]. Despite the advancements in AI and machine learning to improve public transportation accessibility, several key challenges persist. Highlighting projects like Evelity Navigation App, an innovative indoor and outdoor wayfinding application designed to enhance mobility and autonomy for people with disabilities, and WayFinder [92] can transform public transit into a more inclusive space.

One of the primary challenges is the inconsistency and bias in AI training datasets. AI models often rely on publicly available or crowd-sourced imagery (e.g., GSV), which may not capture the most updated or representative accessibility conditions in all regions. The differences in infrastructure, climate, and urban planning across cities can result in inconsistent data that hampers the performance of AI tools. For example, lower-resolution images from older GSV or incomplete datasets from under-surveyed areas can lead to inaccurate conclusions about accessibility features like sidewalk conditions or the availability of curb rampage, which is the integration of AI solutions into existing urban planning and policy frameworks. Moreover, bias in data collection, where urban centers are more frequently mapped than suburban or rural areas, can lead to uneven accessibility insights and policy implementations.

Other issues are inappropriate training and incomplete data, which can directly impact the accuracy and reliability of AI-driven assessments [93]. Research has reported that ML models require large datasets with high accuracy, resolution, and completeness to identify barriers and propose solutions effectively [94], [95]. Transferring data to and from centralized cloud servers is crucial in enhancing public transportation accessibility through advanced AI and ML models [96]. However, reliance on centralized processing introduces challenges related to latency, data privacy, and infrastructure limitations, highlighting the need for more efficient and decentralized AI solutions. Future research must focus on equitable, high-quality AI training frameworks that ensure comprehensive, up-to-date, and inclusive dataset representation. Also, it must explore decentralized AI solutions to address data privacy and infrastructure challenges across diverse urban and sub urban environments.

While tools like deep learning-based image analysis can detect barriers (e.g., uneven sidewalks, missing curb cuts), AI alone is not a solution. Integrating AI with real-time, crowd-sourced data from mobile applications and IoT-enabled urban infrastructure presents an opportunity for dynamic accessibility monitoring. For instance, combining LiDAR-enabled smartphone applications with federated learning approaches can enhance privacy-preserving data collection while improving sidewalk and transit stop accessibility assessments. Such an approach could enable AI to adapt to environmental changes dynamically rather than relying on static datasets.

Moreover, ethical considerations and policy integration challenges remain largely unaddressed in AI-driven accessibility research. As machine learning algorithms increasingly inform urban planning decisions, policymakers must implement regulatory frameworks to validate AI-generated insights before enforcing infrastructural changes. A collaborative approach that combines AI-driven analysis with community participation, where individuals with disabilities contribute firsthand insights, could enhance the reliability and real-world applicability of AI-generated solutions.

Emerging AI techniques such as self-supervised learning (SSL) and multimodal AI fusion can further enhance public transportation accessibility. SSL techniques allow AI models to learn from unlabeled data, potentially improving AI-driven accessibility understandings in underrepresented areas. Similarly, integrating multimodal AI, where different types of data (satellite imagery, IoT sensor feeds, social media reports) are processed together, can create a more comprehensive urban accessibility model.

IX. CONCLUSION

The national and international laws insist on protecting the full and equal rights of people with disabilities all around the globe. This study presented the state of the art on improving the accessibility of people with disabilities to health, education, employment, and other daily needs via the public transport system. A detailed systematic review was conducted using the keywords "Public transport system, disabilities." Different methods of calculating the accessibility were explained. The universal barrier in a typical journey by a person with disabilities was explained. The key features of a successful transportation system were identified. The following major conclusions were drawn from this study.

- The keywords associated with 'Public transport system, disabilities' manifested six clusters when analyzed by VOS viewer. Cluster 1, depicting the widespread keywords ("Public transport", "disability", "transportation", "accessibility" "Public policy" and "United States") was the densest of all the clusters. This observation shows the importance of accessibility for disabled persons and public policy for normal societal conditions.
- There are two widely used approaches to calculating accessibility: (1) accessibility of opportunities or absolute accessibility; (2) accessibility to opportunities. The two concepts differ because the former considers the facility's physical features to allow navigation. In contrast, the later examines the surrounding public space concerning the targeted facility. The current study focused on the later.
- This study categorized five types of barriers: inaccessible infrastructure, information and communication barriers, attitudinal barriers, economic attitudinal barriers, and safety and security barriers that people with disabilities typically experience. The case studies of various localities and satisfaction levels of people with disabilities are presented. These case studies can be used to figure out the critical problems disabled people face in designing successful transportation systems and travel chains.
- The case studies analyzed in this study highlight how accessibility challenges vary across different countries and transport systems. Developed nations have made progress in improving transport accessibility, but gaps still exist, particularly in infrastructure and information accessibility. In contrast, developing countries face more severe challenges due to limited public transport infrastructure, lack of policy enforcement, and economic constraints. In such regions, improving mobility for disabled individuals requires a multi-faceted approach. Enhancing pedestrian infrastructure, ensuring affordability, and incorporating accessibility features in transport services can significantly improve their travel experience. Additionally, raising awareness among transport operators and implementing supportive policies can help create an inclusive travel environment. Without these improvements, many disabled individuals in these regions remain excluded from essential services like employment, healthcare, and education, further deepening social and economic disparities. The lessons from these case studies emphasize the urgent need for localized solutions tailored to the specific barriers faced in different regions.

While our study offers important findings, there are some limitations. We did not conduct a formal risk of bias assessment, which may affect the interpretation of some findings. Some relevant articles and case studies might have been missed due to database limitations and keyword selection. Furthermore, we focused on academic literature and did not include reports or policy documents, which could offer valuable insights into real-world barriers and policy-driven solutions. Lastly, we did not utilize a specific quality assessment tool except for inclusion and exclusion criteria; future studies can employ tools such as the Cochrane Risk of Bias Tool or the PRISMA guidelines, which will provide a more standardized framework for assessing and evaluating selected studies.

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