Smart Public Transport Accessibility

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1 Abstract

This research is a study of the need for improved accessibility solutions for People with Disabilities (PwD). We advocate for the importance of modern solutions using technology to improve mobility and independence for Persons with Disabilities in the public domain. With an emphasis on Public Transport facilities (such as buses, trams, trains, metros, etc.), we analyze the challenges that come with designing systems that cater to a diverse spectrum of users. Technologically driven solutions, such as the use of Cyber-Physical Systems (CPS) and Internet of Things (IoT), pave the way for smarter cities and transport facilities. In this paper, we study existing and proposed solutions in order to propose our own model of how transport accessibility can be improved for Persons with Disabilities.

1.1 Keywords

Cyber-Physical Systems (CPS), IoT (Internet of Things), People with Disabilities (PwDs), Smart Transport

2 Introduction

The need for public transport accessibility primarily stems from the desire to improve financially and physically independence. Accessibility is the key to independence, particularly when it comes to meeting the requirements of children, elderly people, and Persons with Disabilities (PwD). According to a WHO estimate from 2016, there are more than one billion persons with disabilities worldwide. [9].Since then, it's likely safe to believe that number has only gone up. It is only natural for public transportation to embrace technological solutions to solve accessibility requirements in order to increase inclusivity and equitable opportunity for all people, since technological improvements are dominating many industries.

Considerable obstacles to receiving services include [2]:

- Availability and physical accessibility of transport

- Cost
- Services and activities located in inaccessible places
- Safety and security
- Travel horizons (unwilling to travel or do not know about services)

Let's first justify the importance of this study by understanding who we are building solutions for.

2.1 Accessibility Challenges and Technological Solutions

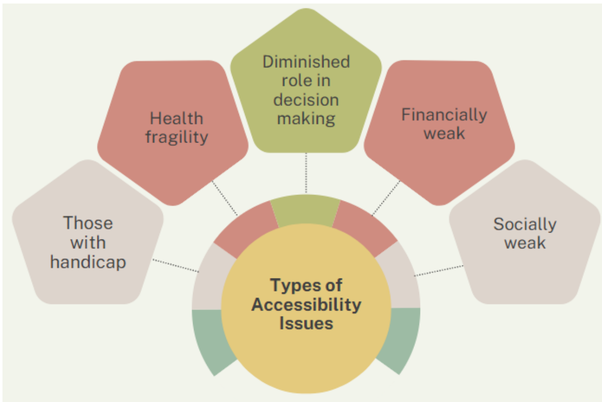

Figure 1: The types of accessibility issues to address [6]

2.1.1 Those with handicap

Creating a cyber-physical system (CPS) network for individuals with disabilities by integrating accessible Internet of Things (IoT) devices and sensors that **respond to voice commands, gestures, or assistive technology inputs.** Ensure seamless connection for real-time control and monitoring between the network and physical devices (such automatic wheelchairs or smart home systems).[6]

2.1.2 Health fragility

Ensuring accessibility, including **real-time health monitoring for emergencies**, and enhancing assistive devices for dependability and efficiency are all part of health fragility in CPS-based transport for people with disabilities. CPS can improve inclusivity by implementing intelligent, self-governing systems. Continuous health monitoring and assistive technology depend on energy efficiency. .[6]

2.1.3 Diminished role in decision making

Due to limited access to adaptive technologies or insufficient inclusion in the design process, people with transport disabilities may have a reduced role in decision-making when it comes to cyber-physical systems (CPS). As a result, they may have less influence on their own mobility and be less involved in determining how to improve the system. To provide **equal possibilities for decision-making, inclusive design and accessibility** are essential.[6]

2.1.4 Financially weak

For those with disabilities who are having financial difficulties, you can provide accessible and affordable mobility options by including **subsidies for public transportation and wheelchair-adapted cars**. To ensure real-time accessibility feature upgrades and improve route planning, use cyber-physical systems (CPS). To schedule and keep an eye on transportation services, employ **voice-activated and intuitive mobile apps**.[6]

2.1.5 Socially weak

Provide a transportation system that is accessible to the disabled and socially disadvantaged through a cyber-physical system (CPS). For wheelchair-accessible mobility, use **voice-guided assistance and IoT-enabled smart sensors to obtain real-time information on accessible roads and vehicles**. Make accessible and affordable services available to socially vulnerable populations. [6]

A stronger push for a safe transportation system is needed because there are a lot of facilities nowadays that do not cater to individuals with impairments. Therefore, increasing the mobility of transportation for those with disabilities can significantly improve their quality of life by giving them greater access to social activities, healthcare, and education. The primary goal is probably to be able to afford to live in places where disabled individuals may easily access social services.

2.2 Cyber-Physical Systems (CPS)

A Cyber-Physical System is one that combines computer and physical components to monitor and manage physical processes. It entails combining technologies like smart sensors, wireless communication, and improved computing power. [8]. Technological developments in areas like smart automation, robotics, smart agriculture, and of course, smart transportation are driven by the harmonious fusion of several sectors. Reactive computing, network connectivity, concurrency, robustness and dependability, real-time application, and—above all—safety-critical applications are some of the characteristics that define a CPS.

2.2.1 CPS in Smart Public Transport

Cyber-Physical Systems (CPS) in the field of public transportation have advanced significantly as a result of the growth of urban and rural infrastructure. As is well known, CPS enables real-time interaction between people, machines, and the environment by integrating computational and physical systems. Traditional urban transportation systems are being transformed into intelligent networks that are more accessible, responsive, and efficient as a result of the integration of computational power with physical components. [10].

An application of CPS has the potential to improve availability and flexibility in public transportation accessible for people with disabilities (PwD). Public transportation systems have historically faced numerous **obstacles to flexibility, such as inadequate infrastructure, a dearth of real-time information, and difficulties in regulating urban areas.** By integrating **smart sensors, actuators, transducers, communication networks, and real-time data processing** to provide rapid transportation and an environment, CPS-encouraging solutions offer chances to handle these problems [7].

Some potential challenges however include: data security risk, cyber-physical system technologies that are frequently out-of-date, and transportation systems.[10]. Let's examine some of the suggested and existing approaches to the accessibility and intelligent transportation issues.

3 Literature Survey

This this section, we shall analyze various papers that touch the subject of smart transport accessibility, particularly for People with Disabilities. Although research in this field is somewhat limited, there have been valuable contributions that delve into the importance of accessibility solutions. The implementation of Cyber-Physical Systems is not very extensive, however let us examine existing research before we propose a model of our own.

3.1 Existing and Proposed Solutions for Accessibility

A study by Venter et al. (2000) describes the contributions of status quo in countries with regards to assessing the access needs of people with disabilities, as well as identify the best initiatives that counties can put into practice, along with a set of guidelines on how we ca reduce mobility barriers in urban communities. The paper addresses the lack of access to transportation and mobility for disabled individuals in urban areas, and how this perpetuates poverty and socio-economic exclusion. They analyze current accessibility practices such as policy and legislation, advocacy and planning, vehicle and infrastructure solutions, and training and awareness.

The results on the status quo study highlight major issues such as effective advocacy and transfer of solutions from developed to developing countries can be appropriate with sensitivity. Accessibility must be included as early as the upgrading and planning stages of publicly owned mass transit systems. Solutions must be considerate of not just physical issues, but also regulatory and financial conditions. Low-cost improvements in infrastructure, vehicles and driver practices to improve the accessibility of transport systems [12].

A 2005 publication by Mashirietal. explores the existing initiatives on the front of public transport information provisions to persons with disabilities, accounting for the need for a robust and easily accessible, yet practical solutions. In most developing countries, there is a severe lack of accessibility to reliable public transport information for disabled people. The study proposes the use of low-cost technologies in order to address this issue, suggesting voice-generated electronic systems, tactile maps, and standardized hand signals. The recommended solutions allow for increased independence for disabled travelers, improving information accessibility, in addition to possible cost-effectiveness of suggested technologies. Some design issues highlighted are [5]:

Operational Environment:

- Affordable
- Reliable
- Fixable
- Compatible
- Operable

Social Constraints:

- Literacy of users/passengers.
- Risk of vandalism

The study goes on the explore the inclusion of Voice-Integrated Electronic Systems, Tactile information, and Standardized Visual Signals, in addition to the development of low-cost, universally designed information systems that incorporate the above listed technologies for passengers with disabilities using public transport.

In 2014, Cañal-Fernández and Hernández Muñiz, set out to study and analyze the accessibility of public transport for disabled people using Geographic Information Systems (GIS) and provide a framework for decision-making using spatial data. GIS is an informed system meant to capture, store, analyze and manage spatial and geographical data, integrating multiple data sources.

The use of GIS to merge databases (transportation supply, location of disabled individuals) provides for a data-driven method to assess and visualize the transportation needs of individuals, thus enabling more informed decision-making. It is important, however, to acknowledge that the implementation of GIS calls for high-quality, standardized geographic data, and coordination between multiple administrative agencies [1].

When talking about studies on a less generalized scale, Amarjeet Singh (2015) [11] and Ava Gilder [3] performed analysis of public transport for disabled users in the cities of Ludhiana and Mumbai, respectively. The former focused on assessing the ascertaining the extent to which road transport facilities in Ludhiana are barrier-free for People with Disabilities, bringing to light physical obstacles that hinder their mobility and participation in society. The study's findings identify issues such as inadequate curb cuts, poorly designed vehicles, and a lack of awareness among drivers regarding disability issues.

In order to address these issues, the author evaluates existing road transport facilities using a pre-tested questionnaire designed by Samarthya and the Rehabilitation Council of India (RCI). Recommendations such as government acknowledgement of the needs of the disabled communities, training of staff by transport providers, and clear publication of accessible routes have been made, along with mention of limitations such as limited time, limited area, validation of scoring system and few such studies previously done in India [11].

The second study in India [3], assessed the challenges faced by individuals with cerebral palsy when using public transport in Mumbai for daily travels, addressing the lack of physical and social accessibility in the metropolitan city for People with Disabilities. Similar to the previously discussed paper, this study highlights the need for awareness, policy-level improvements and infrastructure changes, as well as specific recommendations based on qualitative data from interviews with people with disabilities. The study also discusses initiatives in other metropolitan cities in India such as:

Delhi:

- Wheelchair-friendly buses with three doors instead of two,
- Buses with hydraulic lift and extra room for wheelchair parking,
- GPS trackers, CCTV cameras, and panic buttons.

EzyMov, Taxi service:

- Taxi company for wheelchair users
- Functions similar to Uber or Ola, with booking system, hydraulic lifts and sensitised drivers to help passengers.

Goa:

- Wheelchair-accessible school buses

The study also briefly mentions a city a Spain that has been entirely car-free since 1999, as an effort to make everything in the city easily accessibly by walk, especially for it's vulnerable population such as the elderly, people with disabilities, and children [3].

There have also been suggestions made regarding portable shelters, improved ramp and seating design, enhanced signage and communication for the disabled, as well as, ongoing efforts to raise awareness and train public service operators [13]. Low-cost improvements can be prioritized in transport, with universal design for improved accessibility in bus shelters, street crossings, footpaths, and boarding systems, emphasizing the training of drivers and conductors in helping people with disabilities. Long-term effectiveness requires comprehensive implementation and monitoring [6].

3.2 Smart Transport Solutions using CPS

Our discussion so far has focused heavily on non-technological solutions to to transport accessibility for disabled people, and that is because research in this space has only in recent years delved into the integration of Cyber-Physical Systems (CPS) in order to solve the identified problems.

The last described mentioned improved ramp and seating designs, similarly, one research suggests, a ”real-time spread response system” that enhances accessibility by avoiding limitations at wheelchair ramps in localities. PwD may travel more conveniently and safely thanks to this technology, which uses a network of sensors to identify impediments and provide users with real-time information [7]. In order to create Cyber-Physical ecosystems where data flows easily between transport vehicles and urban management, improving both flexibility and safety, smart infrastructure in the form of ”vehicles to vehicles” and ”vehicles to infrastructure” communication is essential.

A 2011 study titled ’Participatory Cyber-Physical System in Public Transport Application’ [4], was conducted in order to develop a CPS that enhanced public transportation through grassroots participatory sensing, allowing users to continue and access real-time travel data. The paper addresses the need for real-time tracking and data sharing by transit agencies in order to simplify travel planning for commuters. The proposed solution is an extensible CPS, called ContriSenseCloud. It includes Service Exchange Platform (SEP), a general platform for exchange of data, and Application-specific Exchange Platform (AEP) which hosts specific applications like ContriSenseBus.

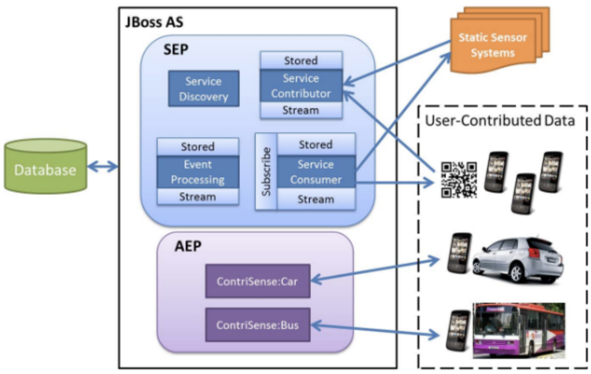

Figure 2: ContriSenseCloud architecture (Arrow indicates data and information flow) [4]

A big advantage of this approach is that it enables real-time travel planning based on data that is contributed by the users, offering a serializable platform that can be adapted for diverse applications. It also facilitates participation from the public, enhancing the quality and richness of data and accuracy of performance. The CPS model was structured as follows:

Client-side:

- Smart phones and static sensors (e.g.,temperature, motion),

Server-side:

- JBoss Application Server,
- MySQL database
- RESTful API

Algorithms:

- Near Real-Time Sensing (NRTS),
- Spatial Data to Bus Stops Mapping (S2B)

Certain limitations to this model though is the dependence on user participation for data, and data privacy [4].

A decade later, Pundir et al. (2022) explored the development, challenges and enabling technologies for CPS-enabled transport networks in smart cities, and how these systems can transform urban mobility, efficiency and infrastructure. Their paper discusses the complexity in deploying a such a system for intelligent transport systems, such as data security, privacy concerns, cyber-attacks, communication reliability, and integrating new CPS technologies with existing infrastructure.

The paper proposes a framework of future of Transport Cyber-Physical Systems (TCPS) for smart cities including: Data sources, Cyber infrastructure and System of Systems. In designing a TCPS, smart sensors, communication networks (E.G., V2X, V2V,V2I), Artificial Intelligence, Edge Computing, and cloud services are all important components used.

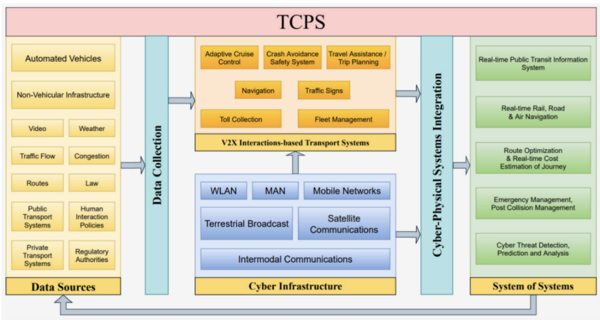

Figure 3: Suggested framework of TCPS for future smart cities [8]

The proposed model consists of a distributed, real-time feedback system utilizing those components to enhance urban mobility and transportation systems. The model includes autonomous vehicles, smart roads, and adaptive traffic management systems. The paper goes into depth designing TCPS, however it does not provide solutions to increase accessibility specifically for People with disabilities [8].

As recently as 2024, a paper discussing a similar real-time distributed feedback system particularly designed to improve transport accessibility for People with Disabilities (PwD) in urban areas. This study primarily addresses the obstruction of wheelchair ramps and other access points meant for PwD due to illegal parking or other blockages, forcing them to take unsafe of inconvenient routes. To overcome this, a distributed sensor network and real-time feedback system was proposed, that will detect and prevent obstructions at wheelchair ramps.

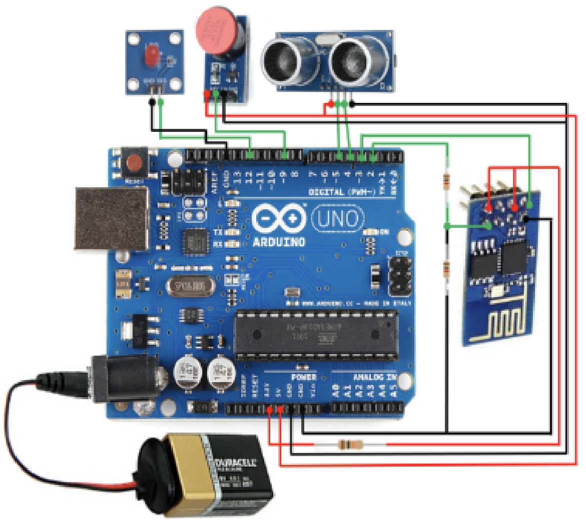

Figure 4: Wheelchair ramp sensor prototype [7]

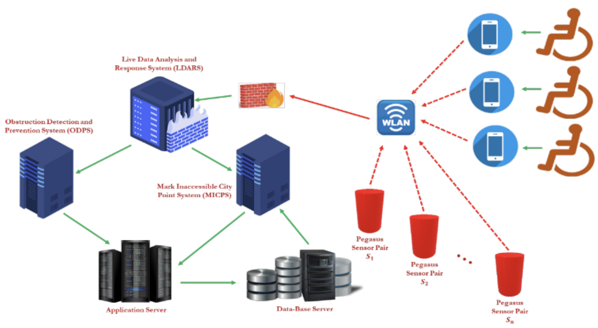

Figure 5: System Architecture [7]

Components such as inaccessibility City Point System (MICPS), a Live Data Analysis and Response System (LDARS), and an Obstacle Detection and Prevention System (ODPS) were included in the system. Users would receive real-time updates and information regarding blocked ramps, allowing them to modify their routes accordingly. Similarly, authorities will also be informed so as to resolve the blockage as soon as possible. This distributed system would enhance data flow and decision-making no accessibility issues, proving to be both salable and innovative, making use of components such as Arduino Uno microcontroller, HC-SR04 Ultrasonic Range Sensor, KS0232 Red LED Module, KS0018 Active Digital Buzzer Module, ESP8266 WIFI Module.

Certain limitations may include high cost of equipment and infrastructure, a reliance of strong network and sensor functioning, and being limited to detecting obstacles in specific areas (e.g., ramps), not addressing broader accessibility issues. Furthermore, it does not solve the issue of lack of accessibility in public transport systems [7].

3.3 Limitations of Currently Available Technology

Technology/Study	Limitations
Accessibility practices (Policy, Infrastructure)	- Transfer of solutions from developed to developing countries is sensitive and challenging. - Accessibility is often not included in early stages of transit system planning.
Low-cost technologies (2005, Mashirietal.)	- Risk of vandalism. - Literacy of users may limit effectiveness. - Operational reliability and compatibility issues.
GIS for Public Transport (2014)	- Requires high-quality, standardized geographic data. - Needs coordination between multiple administrative agencies.
Public Transport in Ludhiana (2015)	- Limited time and geographical area of study. - Limited validation of scoring systems used for assessing transport facilities.
Public Transport for Cerebral Palsy (Mumbai)	- Focused only on physical and social accessibility; broader systemic changes are needed. - Policy-level improvements are slow and not universally implemented.
EzyMov Taxi Service (India)	- Limited reach to users in need due to operational scale. - High dependency on specialized technology (e.g., hydraulic lifts).
Smart Transport Solutions (CPS)	- Dependent on real-time data contribution from users. - Privacy and security concerns. - Difficult to integrate CPS with existing infrastructure. - Vulnerable to cyber-attacks.
TCPS for Smart Cities (2022)	- Does not provide solutions for accessibility issues specific to People with Disabilities. - Data security, privacy, and integration challenges with current systems.

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Table 1

Technology/Study	Limitations
Real-Time Distributed Feedback System (2024)	- High cost of equipment and infrastructure. - Reliance on network and sensor functioning. - Limited to detecting obstacles in specific areas (e.g., wheelchair ramps).

4 Proposed Solutions

Based on our understanding of currently available technology, existing and proposed solutions, and a little imagination, we would like to propose some solutions to the limitations discussed above.

- **Platform Based:** Similar to the pre-booking in EzyMov, we can implement a system where people with accessibility issues may reserve a seat in advance, making it physically inaccessible to regular passengers. This also resolves the issue of there being limited seats in the bus, and regular passengers occupying the seats reserved for elderly, women, or people with disabilities. **Components:** Cloud-enabled system that alerts the transport staff of when and where a person with accessibility issues intends to board the bus. When a passenger boards through the accessibility-door, a sensor can activate the servo motor controlling the physical barrier to the seat reserved for them.
- **Integrate AI-enabled solutions** to alert drivers and passengers of common locations where people with accessibility issues board public transport, e.g., near schools, rehabilitation centers, community centers, public parks, etc.)
- **Use sensors to monitor and maintain maximum capacity**. A big challenge with public transport is over-crowding that makes it difficult for any passenger to travel comfortably. In order to manage this, we can enable sensors that keep track of how many passengers board the bus (either motion sensors detecting each passenger boarding, or optic sensors/cameras tracking distinct on-boarding passengers). Sensors at the exit door can keep track of off-boarding passengers. Together, they can compute and ensure that the total number of passengers does not exceed the maximum capacity. This would also help improve the longevity of public transport vehicle and infrastructure.

As the above proposed solutions are still theoretical, and require an in-depth analysis in order to select the right components and technologies to match our goals- making a representative block diagram would be difficult. However, let's examine their theoretical challenges and advantages:

Table 2: Pros and Cons of Proposed Solutions

Solution	Pros	Cons
Reservation System	- Ensures accessibility by reserving seats and reduces conflict over occupying seats. - Alerts staff in advance to accommodate passengers.	- May cause inconvenience to regular passengers when there is a shortage of seats. - Risk of misuse or vandalism of the physical barrier system.
AI-Enabled Alerts	- Provides and analyzes real-time information, optimizing boarding processes by anticipating demand.	- Requires location-specific data. - Raises privacy concerns and demands data accuracy and driver compliance.
Capacity Monitoring	- Prevents overcrowding and supports efficient load management and safety compliance.	- High cost of installing and maintaining sensors/cameras. - Risk of technical failures affecting monitoring accuracy.

5 Conclusion/ Inference

With all that said and done, now comes the time for us to recap and understand the importance of the studies thus far in the field of Smart Public Transport Accessibility. According to the United Nations Convention on the Rights of Persons with Disabilities (CRPD), Article 9 of the CRPD ('accessibility') states that "...States, Parties shall take appropriate measures to ensure to persons with disabilities access, on an equal basis with others, to the physical environment, to transportation" [3]. Thus, it becomes clear that is is the duty of transport authorities, organizations and governments to put their best foot forward when it comes to improving accessibility of smart public transport.

Current models, though making valuable contributions, are limited to either non-technical solutions, or address a limited spectrum of disabilities. The journey towards complete accessibility is on the horizon. In order to develop real-time Cyber-Physical Systems that:

- Provide real-time information on accessible routes and facilities.
- Integrate with vehicle systems to ensure timely assistance and boarding.
- Use sensors to monitor and maintain accessibility features on vehicles and stations.

References

[1] Verónica Cañal-Fernández and Manuel Hernández Muñiz. An exploratory analysis of disabled people accessibility to urban public transport: the use of geographical information systems. *Investigaciones Regionales-Journal of Regional Research*, (30):79–101, 2014.

[2] Allerdale Borough Council et al. Accessibility. *Retrieved March*, 10, 2005.

[3] Ava Gilder. Public transport in mumbai: challenges faced by the disabled community. *Confluence: Journal of Interdisciplinary Studies*, 2020.

[4] John Kah Soon Lau, Chen-Khong Tham, and Tie Luo. Participatory cyber physical system in public transport application. In *2011 fourth ieee international conference on utility and cloud computing*, pages 355–360. IEEE, 2011.

[5] Mac Mashiri, D Maunder, A Lakra, R Bogopane-Zulu, Denise Buiten, D Boonzaaier, R Zukulu, and Christoffel Jacobus Venter. Improving the provision of public transport information for persons with disabilities in the developing world. *SATC 2005*, 2005.

[6] DAC Maunder, CJ Venter, T Rickert, and J Sentinella. Improving transport access and mobility for people with disabilities. In *CILT Regional Conference, International Logistics and Transport: The Challenges Ahead, Number PA4061/04, Dubai, UAE. Transport Research Laboratory*, 2004.

[7] Iosif Polenakis, Vasileios Vouronikos, Maria Chroni, and Stavros D Nikolopoulos. Towards a real-time distributed feedback system for the transportation assistance of pwd. *arXiv preprint arXiv:2406.06154*, 2024.

[8] Amit Pundir, Sanjeev Singh, Manish Kumar, Anil Bafila, and Geetika J Saxena. Cyber-physical systems enabled transport networks in smart cities: Challenges and enabling technologies of the new mobility era. *IEEE Access*, 10:16350–16364, 2022.

[9] Nandita Saikia, Jayanta Kumar Bora, Domantas Jasilionis, and Vladimir M Shkolnikov. Disability divides in india: evidence from the 2011 census. *PloS one*, 11(8):e0159809, 2016.

[10] Sahed Hossen Sajib. Identifying barriers to the public transport accessibility for disabled people in dhaka: a qualitative analysis. *Transactions on transport sciences*, 1, 2022.

[11] Ruchi Sharma, Manoj Kumar Sharma, and Amarjeet Singh. Evaluation of disable friendliness of road transport facility in ludhiana city of punjab (india). *International Journal of Asian Social Science*, 5(2):73–85, 2015.

[12] CJ Venter, H Bogopane, T Rickert, J Camba, A Venkatesh, N Mulikita, D Maunder, T Savill, and J Stone. Improving accessibility for people with disabilities in urban areas. *Proceedings: CODATU X. Lome*, 2002.

[13] Endang Sri Wahyuni, Bhisma Murti, and Hermanu Joebagio. Public transport accessibility for people with disabilities. *Journal of Health Policy and Management*, 1(1):1–7, 2016.