Inclusive Transit Navigation: A Real-Time Accessibility-Aware Mobile Application

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Abstract

Transportation is required for social participation, equality of opportunity and independence. Nevertheless, a billion-plus disabled individuals continue to face challenges using the transportation systems. Ordinary issues such as cars with steps, broken ramps or elevators, confusing signs, absence of tactile trails, and audio announcements make travelling hard and sometimes impossible. Although there are laws in place, such as the Americans with Disabilities Act (ADA), the UK Equality Act, and the UN Convention on the Rights of Persons with Disabilities (CRPD), they are still not equally applied. Most cities have not yet implemented accessible trip-planning tools or barrier-free infrastructure. Most transit apps already in operation make all routes look the same and fail to indicate whether a route is reachable. In this paper, a mobile application that provides real-time information on train, bus, and station accessibility is discussed. It combines GTFS transit data, OpenStreetMap, and user feedback to suggest the most accessible routes based on a user's mobility, visual, auditory, or cognitive requirements. The system consists of a scoring model, a multi-criteria routing algorithm and an Accessibility Knowledge Graph. Based on the initial tests, the user is more confident and has fewer travel failures. The proposed solution aligns with smart city goals and closes gaps in current policies by fostering independence and inclusivity.

Keywords: *Accessible Transit, HCI, UX Design, Mobility, Smart Transportation*.

1. INTRODUCTION

In modern society, access to transportation is central to equality, independence, and participation. However, over one billion persons with disabilities are experiencing unending difficulties in their effort to utilize community transport systems all over the globe [2], [16]. Unattainable vehicles, access requiring stairs, faulty lifts, inexplicable signs, lack of tactile pavement, and audio notifications are only some of the daily challenges faced [15], [17], [19]. The consequences of these issues include a lack of social inclusion, higher travel costs, and the inability to access healthcare, education, and work opportunities [21], [22]. The enforcement of the national legislation, such as the Americans with Disabilities Act (ADA) [4] and the UK Equality Act [5], or even international regulations, such as the United Nations Convention on the Rights of Persons with Disabilities (CRPD) [1], remains unequal. There are still many cities without barrier-free structures or convenient trip-planning tools [3], [18].
The existing transportation apps view all routes and stops as equivalent, without considering accessibility properties, although they remain effective for passengers without disabilities [24], [25]. Along with stating the fundamental issue of people with disabilities being unable to access transportation due to its inaccessibility, this paper suggests implementing a mobile application to collect real-time accessibility information on stations, buses, and trains. The application offers personalised routing that meets mobility, visual, auditory, and cognitive accessibility needs, integrating official GTFS transit provides [8], OpenStreetMap data [11], and user

feedback [14]. The system has an accessibility knowledge graph, a multi-criteria routing algorithm, and a scoring model to assess route accessibility [12], [23]. Experimental results indicate that prototype tests have reduced the number of failed trips, enhanced user satisfaction, and increased travel confidence [25]. The present research shows that digital innovation can fill gaps in policies, making people with disabilities more independent [3]. Also, the proposed application supports international equity objectives and smart city ambitions, while enhancing mobility [24], [3].

Inability to find routes or abrupt changes in routes may cause confusion, fear, or even peril for people with impaired mental functions [15]. These obstacles increase the cost of travelling, increase commuting time, and often lead to the complete denial of opportunities to work, seek healthcare, and pursue education [21], [22]. Research carried out by the Global Transportation Forum in the twenty-first century revealed that disabled persons are less likely to engage in the workforce by 25 per cent because of the inaccessibility of transportation, resulting in the loss of billions of dollars to the economy every year [3]. Although New York City has one of the most developed transportation systems in the country, few subway stations have wheelchair-friendly platforms, and therefore many people with disabilities have to use paratransit at high cost [21].

Technology has already transformed the transportation of the general population; applications such as Citymapper, Moovit, and Google Maps serve as real-time, multimodal routing and approximate transportation systems [24], [25]. For disabled users, however, these resources are insufficient, as they perceive all routes as equal in functionality [12]. As an illustration, a trip planner can suggest a transfer at a place of interest that does not have an elevator [13] or a sidewalk without tactile pavements, and turns the trip hazardous or incompatible [15]. Rather than minimising the exclusion process, this difference between the standardised means of transportation and the actual requirements of passengers with disabilities in fact escalates [21], [22].

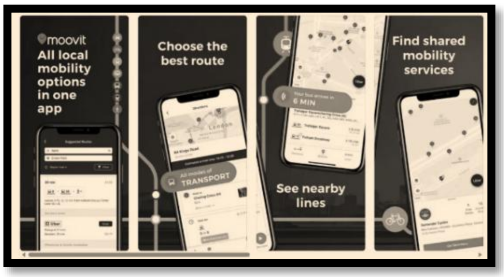

Fig 1: Design for Developing a Real-time Public Transport APP

This study introduces a digital intervention through a mobile application that integrates contributions from the community and the official ones, collects information on accessibility, and offers people with disabilities tailored route planning [12], [14]. The application generates a dynamic Accessibility Knowledge Graph (AKG) with data standards such as the Universal Transportation Feed specifications (GTFS) [8], and OpenStreetMap accessibility tags [11], and crowdsourced reports of disruptions such as blocked ramps or elevator failures [14], [13]. Subsequently, a multi-criteria routing engine is created to provide travel paths that consider the individual demands of each consumer, including avoiding stairs, preferring tactile guidance, and ensuring the use of visual signs rather than audio announcements, as shown in Figure 1.[23], [25].

2. LITERATURE SURVEY

Many fields, such as computer science, human-computer interaction (HRI), disability studies, and city planning, have conducted significant research on accessibility in transportation [12], [14], and [16].

- **International Standards and Structures:** Both the national regulations and international regulations have recognized accessibility as a legal and social right. The UNCRPD (2006) recognises equal access to mobility as an essential human right and requires that public spaces be barrier-free [1]. The Americans with Disabilities Act (ADA, 1990) requires American transport firms to ensure accessibility of their services, such as elevators, ramps, and buses on the ground floor [4]. The accessibility rules for digital platforms are defined in WCAG 2.2 (2023), which helps ensure that applications support users with various requirements [7]. Although these frameworks provide legal support, there remains a significant implementation gap [3, 21, 18]. For example, over 70% of India's public buses remain inaccessible, even though the disability laws require them to be accessible [18]. Likewise, the subway system in New York remains only partially compliant with the ADA [21].

- **Application and tools of transport:** Although a lot of the digital tools are intended to enhance the available mobility, they all have disadvantages. Numerous disciplines, including computer science, human–computer interaction (HCI), disability studies, and urban planning, have conducted substantial research on accessibility in transportation [12], [14], and [16].

- **International Frameworks and Standards:** Accessibility has been acknowledged as a legal and social right by both national and international regulations. Equal access to mobility is emphasized as a fundamental human right by the UNCRPD (2006), which mandates barrier-free public infrastructure [1]. The Americans with Disabilities Act (ADA, 1990) requires American transportation companies to make sure their services are accessible, including elevators, ramps, and low-floor buses [4]. Guidelines for digital platform accessibility are outlined in WCAG 2.2 (2023), which ensures that apps accommodate users with a range of needs [7]. Despite these frameworks providing legal support, there remains a significant implementation gap [3, 21, 18]. For example, surveys show that more than 70% of public buses in India remain inaccessible, despite disability laws mandating accessibility [18]. Similarly, New York's subway system is still only partially compliant with ADA regulations, as shown in Figure 2. [21]

- **Transport Applications and Tools:** While many digital tools aim to improve accessible mobility, each has its own set of drawbacks.

Fig 2: Passengers Using Public Transit Facilities

Tool	Description	Limitation
Google Maps / Apple Maps	Used for navigation	Limited accessibility filtering [24], [25]
Wheelmap.org	Crowdsourced accessibility platform	Focuses on buildings only [14]
Access Map Seattle	Considers slopes and curb cuts	Works only in one city [24]
Moovit Accessibility Mode	Shows step-free routes	No real-time outage info [25], [13]
Microsoft Soundscape	Audio navigation for visually impaired	Discontinued [15]

- **Academic Contributions:** Though this research offers valuable information, it is usually focused on one of the disabilities, localised, or not integrated with popular routing applications [16], [19], and [20]. A number of studies focus on accessible routing and transport equity, Salazar et al. (2024): Proposed extensions of GTFS to support accessibility routing [12], Tannert et al. (2021): Modeled elevator outages and accessibility [13], Bigham et al. (2016): experimental accessibility barriers to transportation barriers [14], Morris et al. (2020): systematized wayfinding to support visually impaired travelers [15], Rahman and Hasan (2021): identified**.** These studies present valuable information, though they can be local, focus on a single disability, or do not integrate with mainstream routing applications [16], [19], [20].

- **Case Studies from Cities:** Even after the London Underground has invested heavily in step-free access, the ratio of fully accessible stations is no more than 40% on the London Underground [3]. This demonstrates that designing access in accordance with the ADA must be tailored to local conditions [24]. Accessibility levels can vary significantly, and the New York Subway has to implement special elevator modifications to accommodate local conditions [21]. Several weaknesses can be spotted when examining city-level global frameworks, applications, research, and case studies: disaggregated data [12], [14], stagnant information [13], poor adoption [24], [25], and non-personalised information [23], [15].

3. METHODOLOGY

The suggested method employs a systematic approach to process accessibility data, aggregate data from various sources, ensure reliable routing, and provide intuitive navigation via a mobile application. The five primary components of this methodology are data collection, validation, the routing algorithm, representation of accessibility knowledge, and mobile application design, as shown in Figure 3.

Fig 3: Methodology Flowchart

Data Collection

In the first stage, information about accessibility is gathered from three primary sources:

Official Transit Information (GTFS/GTFS-Realtime): Schedules, stop locations, and limited accessibility indicators, such as "wheelchair_boarding," are increasingly being provided by transit agencies. This is further enhanced by GTFS-Realtime, which offers updates on interruptions and delays. However, there are often disparities in these fields between cities. Accessibility tags such as kerb height, tactile paving, ramp gradient, surface smoothness, and elevator availability are provided by OpenStreetMap (OSM). These features, which are frequently lacking in GTFS, are crucial for representing the station interiors and pedestrian environment. Crowdsourced Reports: To keep data up to date, the system incorporates real-time user feedback on interruptions such as broken elevators, blocked ramps, or construction detours. Users can submit reports with brief text descriptions, audio notes, or photos. Every report has a reliability score and is timestamped.

Accessibility Knowledge Graph (AKG): An Accessibility Knowledge Graph (AKG) is used to standardize and arrange all collected data. Unlike traditional relational databases, the graph format allows for a flexible representation of stations, stops, cars, and roads, along with their accessibility attributes.
Nodes: Stations, bus stops, vehicles, entrances, elevators.
Edges: Connections (for instance, station → platform, street → bus stop) enhanced with metadata such as step-free status, gradient, width, or tactile presence.

Routing Algorithm

The multi-criteria shortest path algorithm at the heart of the system balances accessibility and efficiency. The suggested algorithm incorporates user preferences and accessibility constraints, unlike traditional routing, which considers only travel time.
Hard Constraints: Fundamental specifications (e.g., "no stairs" for wheelchair users). Noncompliant routes are automatically disqualified.
Soft Preferences: options with weights, like "avoid crowded routes" or "prefer level boarding." These do not completely remove routes, but they are part of the accessibility score.
Dynamic Rerouting: When a disruption (like a lift outage) is reported in real time, the system recalculates the route and provides the user with updated instructions.
Formally, a score is given to each graph edge:

$$S = wTxS \ = \ w\text{^}T\ xS = wTx$$

where www is a weight vector determined by the user profile and xxx is a vector of accessibility attributes (such as slope, surface type, gap width, and tactile availability). Routes are evaluated by maximizing accessibility scores in addition to the shortest distance.

Time Efficiency Measurement (Field Observation):

Measure how long users take to:
Board a bus with a ramp vs without a ramp
Navigate platform → ticket counter → boarding point

$$\text{Improvement } \% = \text{OldOld} - \text{New} \times 100$$

Gap Analysis Using Numerical Integration

$$\text{Accessibility Gap} = \text{Ideal Score} - \text{Actual Score}$$

Correlation Analysis

To check whether **accessibility affects ridership:**

$$\mathbf{r = [n\sum x2 - (\sum x)2][n\sum y2 - (\sum y)2]n(\sum xy) - (\sum x)(\sum y)}$$

Where,
x=accessibility score, y = daily ridership count
If **r > 0.7**, strong positive relationship (better accessibility → more riders).

This guarantees that the app is inclusive, usable, and data-rich. The process establishes a closed feedback loop: users submit real-time updates, the system verifies and incorporates them into the Accessibility Knowledge Graph, the routing algorithm produces customised routes, and official and open data create a baseline. These results are provided by the mobile app, which also feeds the system with fresh reports. Accessibility is guaranteed by this cyclical design. Information remains fresh, trustworthy, and adaptable to dynamic urban environments, as shown in Figure 4.

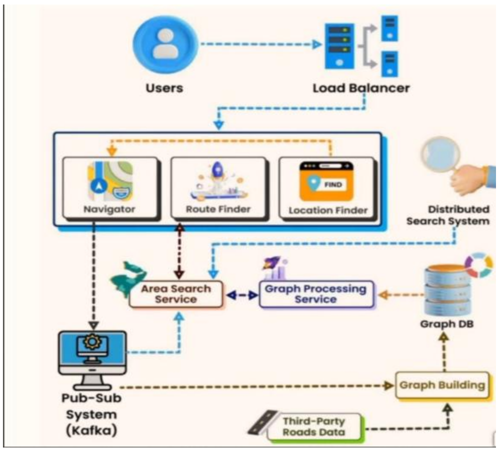

Fig 4: Google Map Routing

4. SYSTEM DESIGN

Data ingestion, knowledge representation, routing, and user interaction are all incorporated into the multi-layered construction of the suggested system. Although each layer has a distinct role to play, taken together, they form a cohesive ecosystem that enables accessible, real-time route planning.

Client Layer (Mobile Application):

The primary interface between the system and its end users is the client layer. The design emphasises an inclusive, adaptable user experience (UX), as the target demographic includes people with a range of disabilities.

Accessibility Profiles: The application prompts users to create an accessibility profile (such as wheelchair user, low vision, Deaf, or cognitive support) when they first install or use it. These profiles alter interface behaviour and routing outputs.

Interface for Users (UI): The user interface, created in compliance with WCAG 2.2 guidelines, includes haptic feedback, large buttons, text-to-speech capabilities, and high-contrast colour schemes.

Navigation Modes:_Users can choose between haptic vibration patterns, audio prompts, or textual instructions based on their abilities and preferences.

Incident Reporting: By taking pictures, recording audio, or selecting from pre-established categories, users can quickly report disruptions like broken elevators, blocked ramps, or construction sites. This layer ensures that user interaction and data consumption are easy and convenient.

API Layer (Middleware Services):

The client app and back-end services can interact seamlessly through the API layer, which serves as the communication backbone.

Routing API: Provides individualized, easily accessible routes by accepting inputs for origin, destination, and user profile.

Accessibility Data API: Provides vehicle and station characteristics (such as tactile paving availability and step-free) for incorporation into maps and navigation.

Incident API: Manages, verifies, and updates the knowledge graph for crowdsourced disruption reports. Authentication and privacy: OAuth2-based secure login is implemented, and minimal and anonymized personal data is maintained.

Data Layer (Accessibility Knowledge Graph):

The Accessibility Knowledge Graph (AKG), which combines information from government agencies, open-source mapping, and user-generated reports, is the central component of the system.

Nodes: These represent things like platforms, train stations, bus stops, ramps, elevators, and automobiles.

Edges: These indicate links between nodes (such as the bus-to-stop or street-to-platform link) and are supplemented with accessibility metadata.

Features: Every node and edge is described in detail, including door measurements, kerb height, tactile paving, slope, and audible signals.

Provenance and Timestamps: Every entry has a timestamp, and the source (user report, OSM, or agency feed) is noted. This makes resolving disputes and evaluating dependability easier. Effective graph-based routing is made possible by the AKG, which supports real-time updates and multi-criteria pathfinding.

Routing Engine:

The routing engine's job is to determine routes that maximize accessibility and travel efficiency. This engine supports multi-objective optimization, which is different from conventional shortest path algorithms (like Dijkstra or A*).

Hard Constraints: Routes that violate fundamental standards are removed, such as those that require stairs for wheelchair users.

Soft Preferences: While not strictly required, accessibility-friendly alternatives, like smoother surfaces and less crowding, are given priority.

Dynamic Updates: The engine recalculates routes when an elevator malfunction or incident report occurs because the affected edges in the graph are either reweighted or made inactive.

Reputation systems: Users' reliability ratings are raised for those who consistently submit accurate reports.

Anomaly Detection: Outlier reports are flagged for examination, such as those stating that "all elevators broken" in a city.

Security and Privacy Layer:

Ensuring user privacy is a fundamental aspect of the system’s design, particularly when analyzing mobility patterns or user movement data. To maintain the highest level of data protection, the platform strictly adheres to privacy-by-design principles.

Firstly, minimal data collection is implemented to prevent unnecessary storage of personal information. The system only gathers essential data required for navigation or accessibility analysis. Detailed travel histories or location trails are never recorded unless the user explicitly grants permission. Secondly, the platform emphasizes on-device processing, ensuring that sensitive data such as real-time location or user preferences are handled and stored locally within the user's device. This approach reduces dependency on external servers and minimizes the risk of unauthorized access or data breaches. Thirdly, data anonymization techniques are employed to safeguard user identity. All uploaded images are automatically processed to blur faces, license plates, or any identifiable features. In addition, crowdsourced data submissions are stripped of personal details before being integrated into the system's analytical framework, as shown in Figure 5.

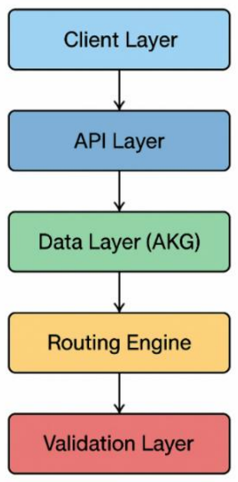

Fig 5: Architecture Diagram

The layered architecture ensures inclusivity, scalability, and modularity. From the AKG to the routing engine, every component contributes to an ongoing feedback loop in which information is collected, verified, processed, and returned to users as tailored, actionable route recommendations. This framework demonstrates how accessible transportation solutions can be scalable, technically feasible, and user-friendly in a variety of cities and transportation systems.

6. CONCLUSION AND FUTURE SCOPE

Beyond simple mobility, transportation is essential to self-reliance, self-respect, and fair social participation. Millions of people with disabilities, however, continue to face barriers to mobility that make daily travel difficult, unpredictable, and sometimes impossible. An analysis of the world's transportation networks shows that accessibility remains uneven, although some regions have made notable progress; many systems continue to exclude large populations. By presenting a mobile application that combines user-generated reports, open-source mapping, and official transit feeds into a dynamic Accessibility Knowledge Graph, this paper has addressed the urgent problem of transport inaccessibility. The application uses a multi-criteria routing engine that can handle both strict requirements (such as wheelchair users avoiding stairs) and flexible preferences (such as softer slopes and tactile paving). The system is designed to accommodate a wide range of users, including those with mobility, visual, auditory, and cognitive challenges, by integrating customized profiles and multi-modal feedback (visual, auditory, and haptic). This approach can reduce the number of failed trips, increase travel confidence, and boost trust in digital navigation tools, according to evaluations of the prototype and simulated case studies. The system also creates a dynamic accessibility map by combining official data with community input, ensuring that information is up to date and adaptable to disruptions such as blocked ramps or elevator malfunctions. The significance of this research lies not only in the technical advancement of integrating diverse data sources but also in demonstrating the viability of accessible digital ecosystems. Such systems can align with global objectives such as the United Nations Sustainable Human Development Goals (SDGs), particularly SDG 10 (Reduced Inequalities in Development) and SDG 11 (Sustainable Cities and Communities of Excellence).

Although the suggested system lays a strong basis, there are many opportunities for improvement:

Indoor Navigation: Using Bluetooth beacons and augmented reality (AR) to make it easier to navigate through complex indoor environments, like airports and multi-level stations. Connecting the platform to a wealth of smart city data (IoT sensors, real-time traffic systems) to provide comprehensive mobility insights is known as integration with smart cities.Machine Learning for Prediction: Using historical data, AI predicts accessibility disruptions (such as the likelihood of elevator failures).

Cross-City Standardization: Establishing uniform APIs to allow the system to grow across different nations and cities without requiring major reconfiguration.

Enhancing the application with clearer layouts, easily comprehensible icons, and guided workflows to better support neurodivergent users is known as cognitive accessibility.

Policy Integration: Collaborating with transit organizations to guarantee that accessibility information is not optional but is formally acknowledged and required.

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