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A Collaborative System Design for Avoiding and Removing the Unexpected Obstacles Encountered during Wheelchair Navigation

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Abstract: In this study, we designed a system that cooperates with users to always provide the most up-to-date map and the most suitable route and to cooperate with disability units to ensure that unexpected obstacles on the route are removed. It is believed that this system will contribute to (1) eliminating obstacles more quickly and preventing other people with disabilities from being aggrieved until the obstacles are removed; (2) increasing awareness of the responsibility towards people with disabilities in society; (3) greater integration of people with disabilities; and (4) increasing the economic and social welfare of society. The design process includes analysis of the current situation, data acquisition, web mapping, mobile application development, and experimental testing phases. The system successfully passed the tests. However, the optimum level of expected benefits of the system depends on users' consistent use of the mobile application complaint tool and authorities' consistent evaluation of the complaints received. As the number of mobile application users increases, the number of complaints will gradually increase, yet after a while, as the awareness and sensitivity of society on this issue gradually increase, the number of complaints will gradually decrease, and the expected benefits will be achieved.

Keywords: collaboration; system design; mobile application; wheelchair navigation; questionnaire

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1. Introduction

People with disabilities as a social group cannot participate in social life as equal individuals. Disability can be defined as cognitive, developmental, intellectual, mental, physical, or a combination of these [1]. Walking on the streets or going from one place to another, which are ordinary actions for people without disabilities, has a different meaning for people with walking disabilities. For them, daily life routines can mean successfully navigating a maze full of obstacles. Many people with walking disabilities constantly encounter obstacles while performing their daily routines and participating in social activities. These challenges make it difficult for people with disabilities to achieve their goals and limit their access to equal opportunities in society. To ensure social justice and protect the rights of people with disabilities, such problems of people with disabilities should be prioritized.

Approximately 15% of the world's population is affected by some form of disability [2,3]. Governments and government agencies have made various advances in the field of policies and guidelines. For example, the United Nations (UN) strategy for the participation of persons with disabilities aims to promote the inclusion of persons with disabilities by advocating for participation, universal design, accessibility, reasonable accommodation, and organizational cultures that support their development [4].

Transportation problems encountered by people with walking disabilities in their daily lives have negative effects on social participation, independence, and quality of life [5,6]. The lack of barrier-free and accessible roads prevents these individuals from moving around safely and comfortably and limits social participation. Such problems as insufficient handicap ramps, broken sidewalks, unusable pedestrian crossings, and vehicles parked in front of handicap ramps make the daily movements of people with walking disabilities difficult and narrow the boundaries of their living spaces.

Assistive Technologies (ATs) play an important role in improving the quality of life, independence, and development of people with disabilities. ATs can be defined as any commercially purchased, modified, or adapted item, component, or system of products used to increase, maintain, or improve the functional abilities of people with disabilities [4].

With the development of mobile devices, mobile-based applications are also being developed. In particular, map-based mobile applications provide users with significant advantages [7]. Routing applications on mobile devices and desktop computers are often used when planning a trip or visiting an unknown location, such as a new city [8]. While an individual's experience helps them to find the shortest or fastest route in familiar places, routing applications replace experience and can help to find the shortest or fastest route in unfamiliar places. Similarly, people with disabilities rely on their knowledge gained through experience about the obstacles in the places where they live their daily lives. However, when moving in unfamiliar places, regular route applications designed specifically for motorized traffic or pedestrians cannot provide the detailed information needed by people with disabilities; in other words, they cannot fully compensate for their lack of experience.

Routing applications designed for non-motorized traffic, such as pedestrians, require different geographic data than applications designed for motorized traffic [9,10]. Different geographical data are likewise required for routing applications to be designed specifically for people with disabilities. Commercial geographic data providers do not offer this detailed information because of the high cost of data collection and maintenance [8].

In a web application, WheelMap, and a mobile application, WheelMate, wheelchair-accessible indoor points of interest are displayed on the map with nominal and ordinal symbols. In both applications, the data source is the users, and users contribute with photos, videos, etc., along with map symbols. Routes are determined by multicriteria algorithms in both applications [11,12]. The mobile application developed by Cardonha et al., is similar in many respects, yet it covers outdoor points of interest [13]. In a web-based study on indoor accessibility in Bologna, Italy, points of interest were presented to users using nominal symbols [14]. A web-based study was also conducted for European capitals, in which outdoor data were collected by users through OpenStreetMap (OSM). In this study, only map symbols were used, and the most suitable route was determined using the map-matching method [8]. The main feature that distinguishes the study [15] from others is the effective use of GPS. A web-based study was also conducted, in which data were collected in a controlled manner through a game presented to users [16]. The system introduced by Prandi et al., is a system that focuses on analyzing indoor and outdoor accessibility requirements and is fed by three sources (data collected by sensors, reports added by users, and reports generated by administrators) [17]. In MAGUS, a web-based navigation service introduced by Beale et al., the optimal routes are calculated based on six routing criteria (shortest distance, fewest obstacles, least slope, avoiding difficult surfaces, using only controlled crossings, and limited road crossings) [18]. A web-based routing tool, U-Access, introduced by Sobek and Miller, aims to determine the shortest routes for people with three ability levels ((1) unassisted mobility, assisted mobility: (2) cane or (3) wheelchair users) [19]. Another study [20] introduces OurWay, a mobile pedestrian navigation prototype with special functionalities for people with limited mobility or parents using strollers. In order to determine personalized routes, one study [21] used an absolute constraint method, whereas another study [22] used a multi-metric algorithm. In the study conducted by Cardonha et al., accessible routes were determined using sensor and crowdsourcing data [13]. As for the EasyWheel application, wheelchair users are supported by review articles [23]. There is also a series of studies on map matching based on four different methods for wheelchair navigation (Chain-Code, Hidden Markov Model, Fuzzy Logic, and Movement Pattern

Recognition) [24–27]. Path 2.0, a navigation service developed in Italy, aims to capture user behavior without any clues regarding their motivations or preferences. For this purpose, the daily movements of a wheelchair user are tracked and presented as accessible paths to another user when desired [28].

The literature review has revealed the following:

- More web applications have been developed than mobile applications.
- Almost all of these applications are intended for assisted mobility users only, and very few are also intended for unassisted mobility users.
- Almost all of these applications offer users the most convenient route, and very few also offer options such as the shortest route.
- Weighting, map-matching, multi-criteria, and artificial intelligence methods were used for route determination.
- As data sources, maps, users, and sensors have approximately equal weights in these applications.
- Most of them are intended for the outdoors.
- Mainly map symbols are used in communication.
- Most of them are not feedback-based; in other words, users are not informed about status changes regarding obstacles.
- In some applications, only nominal; in some only, ordinal; and in some applications, both nominal and ordinal map symbols are used. There is no clear preference between nominal/ordinal map symbols.
- Data entry is open to users in half of the applications and closed to users in the other half.
- Approximately half of the applications are unsupervised and uncontrolled in terms of data entry; therefore, there is no certainty about the accuracy of the disability information presented to users.
- Although most of them are academic studies, there is also a commercial application and social responsibility project.
- None of them have the concept of temporary obstacles, such as a vehicle parked in front of a ramp.
- All but one of them have no obstacle tracking;
- All of them are informational rather than solution-oriented; they do not at least have components that will ensure the removal of temporary obstacles.

In conclusion, there are various mobile applications that support people with walking disabilities in many ways, but none of them provide complaint management. There is no system that ensures that unexpected obstacles encountered during wheelchair navigation are reported to the relevant units, monitors the process, informs all users about the obstacle in question at every stage of the process, and informs the complainant separately at the end of the process. However, almost every institution now has a disability unit. The questionnaire study also showed that people with disabilities also have such demands. Therefore, in this study, a collaborative system that included complaint management was designed.

2. A Collaborative System Design

This section explains how to create a mobile application that not only contains up-to-date maps showing obstacles and creating routes where obstacles are taken into account but also a system that reports users' complaints to responsible and authorized persons and tracks them; that is, it establishes a relationship between users and responsible and authorized persons.

The lifecycle of this system, which will be referred to as e-Rota (for "engelsiz Rota", which means "barrier-free route") from now on, is shown in Figure 1. The lifecycle starts when a complaint is registered by a user, for instance, when reporting a vehicle parked in front of a ramp. The complaint registration is automatically saved in the database. The system administrator, who sees the complaint in the database, both updates the map (placing an obstacle symbol at the location of the ramp on the map) and sends the complaint registration via e-mail to responsible and authorized persons to remove the obstacle. The responsible and authorized persons receiving this e-mail take the necessary action to remove the obstacle and send an e-mail to the system administrator after the obstacle is removed. Learning that the obstacle is removed, the system administrator updates the map again; in other words, they remove the obstacle symbol placed at the location of the ramp on the map and send an e-mail to the user.

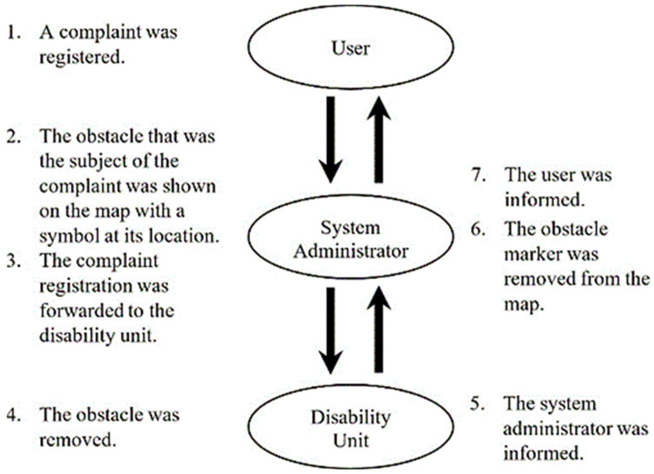

Figure 1. e-Rota lifecycle.

The design of this system began with a questionnaire study to analyze the current situation. After the questionnaire results showed that there was a need for such a system, the stages of collecting the necessary data, creating a web map, and developing the mobile application were initiated. Finally, the system was tested, and the results were evaluated.

2.1. Current Situation Analysis

Current situation analysis is a prerequisite for a good design. In this study, the data required for the current situation analysis were collected using a questionnaire [29]. The questionnaire was reviewed and approved by the Atatürk University Science and Engineering Sciences Ethics Committee. A total of 77 people with walking disabilities from 26 provinces participated in a face-to-face questionnaire via Google Forms. Permission to use the data collected in this study was obtained from the participants during the questionnaire. The Turkish Disabled People's Association significantly contributed to reaching the participants. The answers to the questions are provided in Appendix A.

The analysis of the questionnaire results showed that people with disabilities have the following main problems and expectations:

- They do not know where they will encounter obstacles while going from one place to another or what kinds;
- Sidewalks without ramps, permanent and temporary obstacles that render existing ramps unusable, and inappropriate ramp slopes are frequently encountered problems;
- They prefer routes with fewer obstacles, even if they are longer;
- They want to use applications, yet the existing applications do not meet their expectations;
- They need applications that can show obstacles on the map, create barrier-free routes, and show public transportation vehicle stops suitable for people with disabilities;
- They want to report their complaints about the obstacles they encounter to relevant units;
- It would be beneficial if complaints about obstacles could be reported to relevant units easily and quickly with the help of an application;
- Maps, voice recordings, and photos would be more useful when reporting complaints about obstacles to relevant units with the help of an application;
- They have no clear preference for their names being included in complaint registrations;

- They want to know whether necessary action has been taken regarding their complaints.

2.2. Data Acquisition

In order to create the geometric infrastructure of the e-Rota, first of all, sidewalks, ramps, pedestrian crossings, and bus stations in the study area were measured with the help of the Garmin eTrex Vista GPS receiver, which is manufactured by Garmin Ltd. in Olathe, KS, USA, and thus a set of points with known geographic coordinates in the WGS84 datum were obtained. After these points were positioned in the Universal Transversal Mercator (UTM) projection (Zone: 37) in the NetCAD 8.5 environment, a cartography software, point and line features representing sidewalks, ramps, pedestrian crossings, and bus stations were created. The point and line features were topologically structured in the ArcGIS 10.6 environment, a GIS software, and exported in the KML format for inclusion in Google Maps, the base map for e-Rota. The KML file was included in Google Maps, and red exclamation symbols were manually placed at the endpoints of the sidewalk, where there were no ramps.

The study area was Atatürk University's main campus in Erzurum, Türkiye. The campus surface area is approximately 6.5 km^2. In addition to faculties, social facilities, a library, etc., there is also a hospital on campus. Therefore, thousands of people from all age groups come to the campus together with students every day. Some of them are people with disabilities who use wheelchairs. Studies on people with disabilities were carried out by the Disabled, Elderly and Veterans Research and Application and Research Center of Excellence affiliated with the Rectorate. The study area and aforementioned data are presented in Figure 2.

Figure 2. The study area and data.

2.3. Web Mapping

The content on the web page was specified in three different languages in Microsoft Visual Studio Code: HTML (Hypertext Markup Language), CSS (Cascading Style Sheets), and JavaScript. First, a standard Google Map was added using the Maps JavaScript API.3.

The point and line features representing the sidewalks, ramps, and crosswalks, in addition to the symbols representing the endpoints of sidewalks without ramps in the KML file, were imported by means of a function in the script. Two controls (zoom and pan) were made visible.

After symbols representing bus stations were located, the Start and Reset buttons were added and made functional. In addition, the necessary arrangements were made to ensure that it had the following functions: (1) determining a user's location and displaying it on the map, (2) determining a destination and displaying it on the map, (3) determining the shortest barrier-free route from the user's location to their destination according to Dijkstra's algorithm and displaying it on the map, and (4) placing yellow exclamation symbols at the locations of the obstacles complained about. Thus, the web side of the system was achieved (Figure 3).

Figure 3. The web side of the system.

Google Maps determines the shortest route according to Dijkstra's algorithm and the A* algorithm using a graph created based on its own road network [30]. In other words, in Google Maps, analysis of the shortest route cannot be performed on a road network that has been added by others, as in this study. Therefore, in this study, a new class was created by creating a graph based on the data in the KML file added to Google Maps (in other words, determining the nodes and edges of the graph) and determining the shortest route based on this graph, according to Dijkstra's algorithm.

2.4. Mobile Application Development

The e-Rota mobile application was developed on the Android Studio platform using the Kotlin programming language. Android version 11 was chosen to ensure that the application would support both current and older versions.

Firebase, a real-time cloud database, was preferred because the records to be created by users (users' e-mail addresses, complaint subjects, locations, photos taken by users, and users' written descriptions) need to be tracked and evaluated by system administrators and disability units.

Interface designs were made with the help of the Figma design tool. On the login page created using the Google Firebase Authentication plugin, users can register and log in to the system using their e-mail addresses (Figure 4a). On the home page, users have two options to switch to the navigation screen or the complaint screen (Figure 4b). On the navigation screen, the web map is opened and presented to the user with all of its functions. Once a destination is determined, the user's current location is accepted as the starting point, and the most appropriate route is determined and presented to the user (Figure 4c). Descriptions of the symbols on the map are presented to the user on the legend page (Figure 4d). On the complaint page, the user is first asked to select or enter the subject of the complaint (Figure 4e). This step is followed by a page where the user can take a photo of the obstacle that is the subject of the complaint and provide a written explanation (Figure 4f).

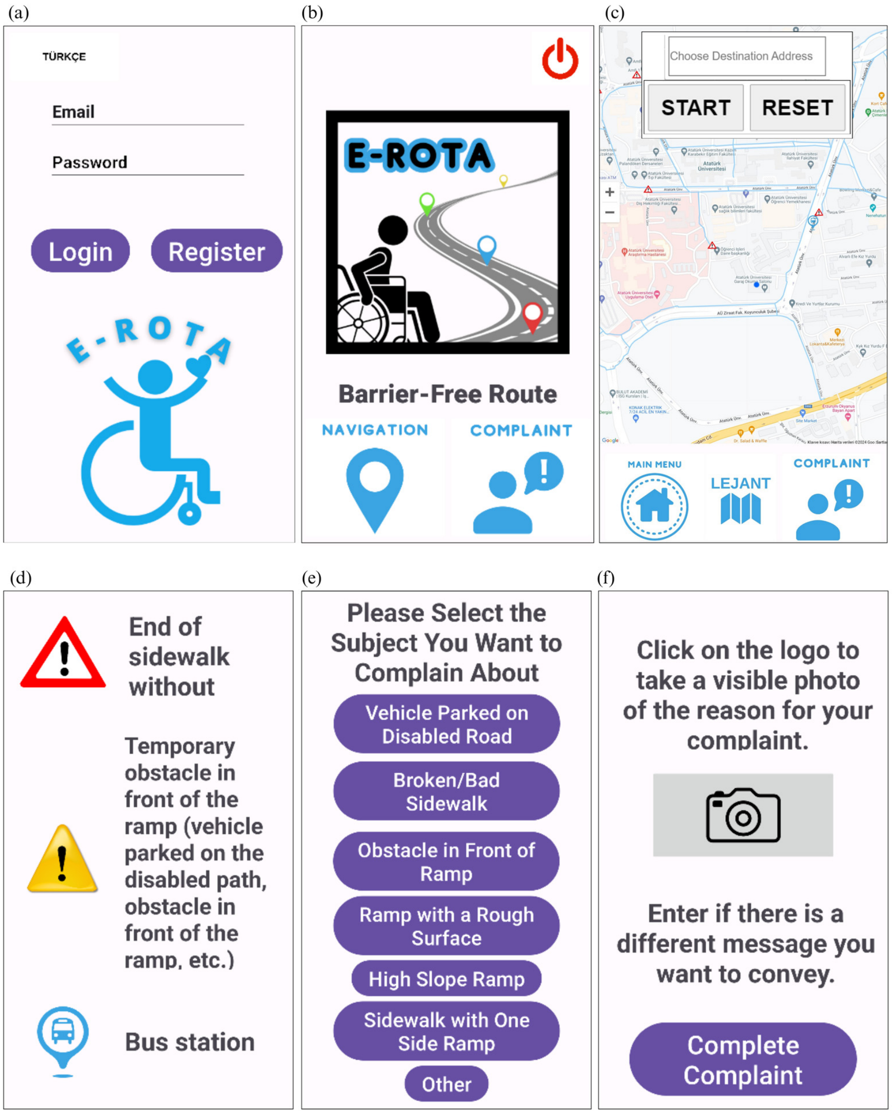

Figure 4. Login (**a**), home (**b**), navigation (**c**), legend (**d**), complaint (**e**), and photo/message (**f**) screens of the mobile application.

2.5. Experimental Testing

The system was tested with seven participants on 18 February 2024. One user set his location (University Guest House) as the starting point and Campus Dining Hall as the destination. While moving along the route determined by the application, the user saw a car parked in a way that prevented the use of a ramp in the Anıtlar area and registered a complaint at 13:15 (Figure 5a,b). The system administrator, who received the complaint through the Firebase database system, updated the map at 13:20 and forwarded the complaint to the disability unit via e-mail (Figure 5c,d). Upon receiving the e-mail, a disability unit official visited the complaint location, contacted the car owner, had the car removed from its location at 13:45, and sent a photo showing that the obstacle had been removed to the system administrator's e-mail address (Figure 5e,f). The system administrator, who received the e-mail sent by the disability unit official, updated the map again at around 14:00 and sent an e-mail to the user who registered a complaint (Figure 5g,h). Thus, the problem was solved in approximately 45 min and the system was found to work smoothly.

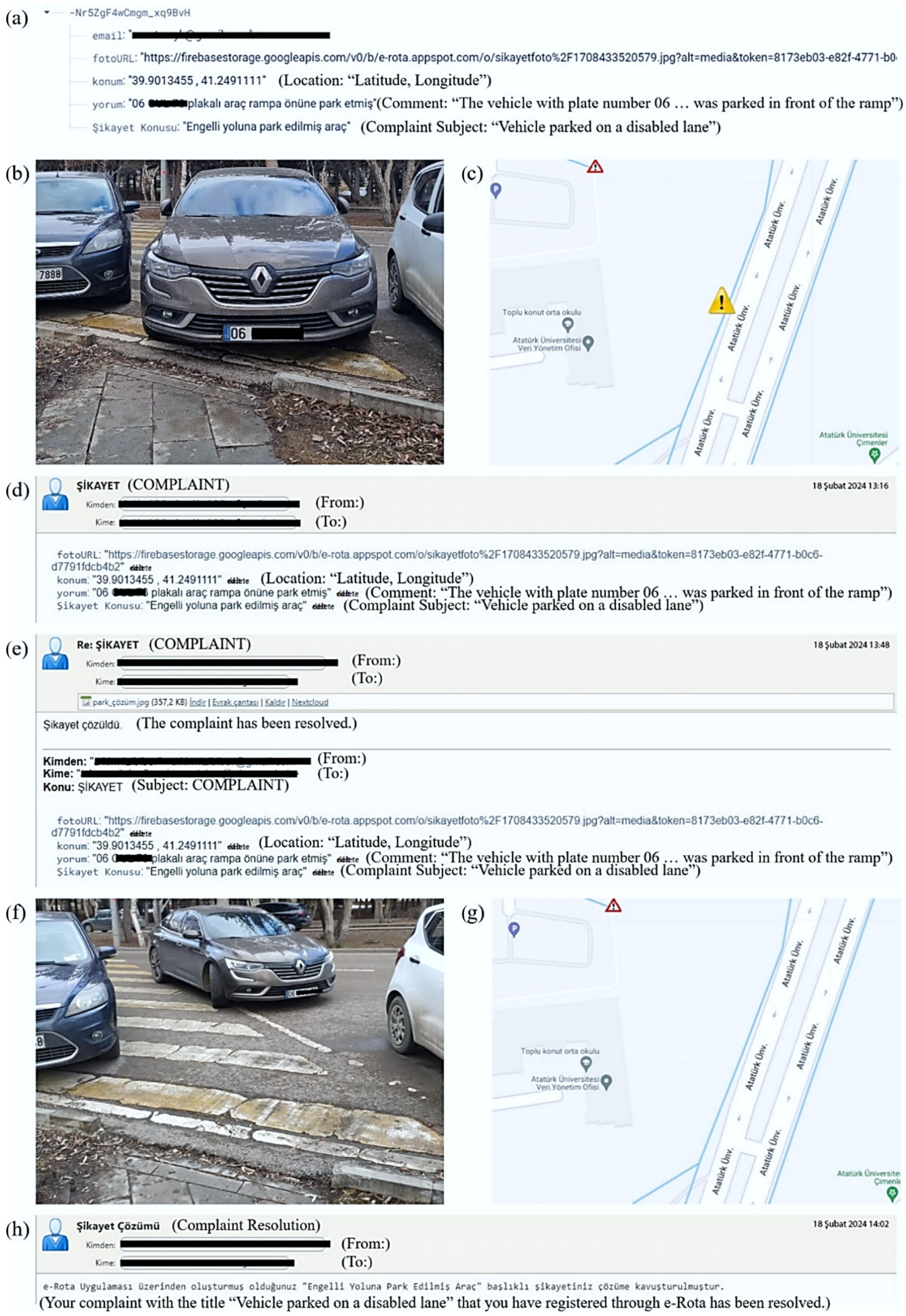

Figure 5. The experimental testing stages: a complaint including a photo showing the obstacle was registered by the user (**a**,**b**), a symbol showing the obstacle was located on the map by the system administrator (**c**), the complaint registration was forwarded to the disability unit by the system administrator (**d**), the obstacle was removed and the system administrator was informed by the disability unit (**e**,**f**), the symbol showing the obstacle was removed from the map by the system administrator (**g**), and the user was informed by the system administrator (**h**).

3. Conclusions

In this study, a new system was designed that cooperates with users in detecting obstacles and with disability units in removing obstacles. By means of these collaborations, (1) users are informed about unexpected obstacles; (2) routes passing through the obstacle points are not suggested on the map until the obstacles are removed, thus preventing other users from encountering the same surprise and experiencing the same grievance; (3) the removal of these obstacles is ensured; (4) after the obstacles are removed, users are informed on the map, and routes passing through these points can be suggested to users again, thus avoiding the unnecessary extension of users' routes. As a result, thanks to cooperation, a system has been developed that will always convey the most up-to-date information to its users, determine the most suitable routes for them, be a means of quickly reaching authorities for the removal of unexpected obstacles, and contribute to preventing loss of labor and time, raising public awareness, being more sensitive to people with walking disabilities, becoming a more regulated society, and thus contributing to social peace.

The tests showed that there was no problem with the mobile application and system design, and the goal was achieved. When the system administrator learned that there was an obstacle through the developed mobile application, the system administrator immediately updated the map, the relevant unit official removed the obstacle, and the system administrator updated the map again. Between the two updates, people with disabilities using this mobile application were assigned different routes that did not include this obstacle, and many problems, such as loss of time and effort, were avoided.

The success of the system depends on its components (people with disabilities, system administrators, and disability units) fulfilling their duties on time and completely. The more people with disabilities use the mobile application and the more system administrators and disability unit officers fulfill their duties in a timely and complete manner, the more efficient the system will become. As the use of the mobile application increases, there will be numerous benefits, such as providing more up-to-date maps and more suitable routes, increasing awareness and sensitivity in society as recognition of the application and the system increases, decreasing obstacles as awareness and sensitivity in society increase, and enabling people with disabilities to perform their daily routines more smoothly as obstacles decrease, thus creating a more peaceful society.

The next goal of this study is to provide the necessary promotions and support for the development of this prototype mobile application and system to cover the entire country.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of Atatürk University (protocol code: E.60665420-000-2200302484; date of approval: 29 September 2022).

Informed Consent Statement: Informed consent was obtained from all the subjects involved in the study.

Data Availability Statement: The original contributions presented in the study are included in the article; further inquiries can be directed to the corresponding authors.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A. The Questionnaire

1. Your age?
    - 0–12: 1.3%
    - 12–18: 2.6%
    - 18–40: 55.8%
    - 40–65: 37.7%
    - 65+: 2.6%
2. Your marital status?
    - Married: 39%
    - Single: 61%
3. Your education status?
    - Primary education: 9.1%
    - High school: 27.3%
    - Undergraduate: 51.9%
    - Postgraduate 11.7%
4. Your gender?
    - Male: 64.9%
    - Female: 35.1%
5. Are you working?
    - Yes: 37.8%
    - No: 62.2%
6. Your profession?
    - Academician: 1
    - Officer: 10
    - Branch Manager: 2
    - Technician: 2
    - Shopkeeper: 2
    - National Athlete: 1
    - Engineer: 2
    - Private Sector: 2
    - Laborer: 3
    - Teacher: 1
7. Which province do you live in?
    - Aksaray: 1
    - Ankara: 2
    - Antalya: 2
    - Aydın: 1
    - Balıkesir: 1
    - Bursa: 4
    - Erzincan: 1
    - Erzurum: 38
    - Eskişehir: 1
    - Gaziantep: 1
    - Hakkâri: 1
    - Hatay: 2
    - Iğdır: 1
    - İstanbul: 4
    - Kars: 1
    - Kayseri: 1
    - Kocaeli: 1
    - Konya: 2

- Manisa: 1
- Mersin: 1
- Muğla: 2
- Ordu: 1
- Sakarya: 1
- Samsun: 2
- Şanlıurfa: 2
- Trabzon: 1
- Van: 1

8. Your place of residence?
    - Village: 7.8%
    - District: 2.6%
    - Sub-province: 23.4%
    - Province: 66.2%
9. What is the degree of obstacles you encounter during your transportation?
    - I encounter so many obstacles: 48.1%
    - I occasionally encounter obstacles: 33.8%
    - I don't encounter any obstacles: 1.3%
    - I don't encounter many obstacles on the routes I know, but I encounter many obstacles on the routes I don't know: 16.9%
10. Please indicate the assistive item you use due to your disability while moving.
    - Wheelchair: 50.6%
    - Walker 1.3%
    - Cane: 16.9%
    - I don't use any assistive items: 29.9%
    - Other (if this is selected, you will be asked to enter what it is): 1.3%
11. Which one do you pay more attention to when determining a route for your transportation?
    - A shorter distance: 31.2%
    - Fewer obstacles: 68.8%
12. Would you like to inform the relevant institutions and register a complaint when you encounter a problem during your transportation?
    - Yes: 84.4%
    - No: 5.2%
    - I have no idea: 10.4%
13. Would you like to have a mobile application to inform relevant institutions and register a complaint when you encounter a problem during your transportation?
    - Yes: 90.9%
    - No: 1.3%
    - I have no idea: 7.8%
14. When you encounter a problem during your transportation, what would you prefer to use to inform the relevant institutions and register a complaint through mobile applications? (More than one option can be selected.)
    - A map showing my current location with an indication of the problem I encounter: 51.9%
    - Audio recording: 29.9%
    - Video recording: 53.2%
    - Photograph: 49.4%
    - Available buttons: 28.6%
    - Text: 26.0%
    - Other (if this is selected, you will be asked to enter what it is): 2.6%
15. Would you like your name to be mentioned in the complaints you will register?

- Yes: 50.6%
- No: 49.4%

16. Would you like to be informed about the resolutions of your complaints?
    - Yes: 88.3%
    - No: 11.7%
17. Do you use any applications to facilitate your transportation?
    - Yes: 20.8%
    - No: 79.2%
18. What are the applications you use?
    - Google Maps
    - EGO Cepte
    - Kardelen Kart
    - Navigation app
    - Smart tickets
    - Spots in public transport
19. What kind of convenience does the application you use provide for your transportation?
    - It shows bus locations, times, bus station names, bus stations, and routes.
    - Fast and easy transportation.
    - It helps me find my route.
20. Do you think the application you use has any shortcomings? If so, what are they?
    - Mobile complaint box.
    - They are not exactly geared towards people with disabilities. For example, you can see pedestrian crossings and bicycle paths, but it does not show whether they are suitable for a wheelchair user or a visually impaired person. It does not indicate whether places such as public institutions or public congress centers, multipurpose halls, theaters, cinemas, etc., are suitable for wheelchair users.
    - It should be able to provide routes for people with disabilities and show locations where there are sidewalks for people with disabilities and barrier-free bus stations.
    - It does not show obstacles.
21. What are the factors that make your transportation difficult?
    - Lack of ramps
    - Sidewalk surfaces
    - Empathy
    - Obstacles in front of ramps
    - Ramp slopes
    - The law is not followed
    - Traffic
    - Uncertainty
    - Regulatory agencies
    - Sidewalk width
    - Constant dependence on others

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