Development of Route Accessibility Index to Support Wayfinding for People with Disabilities

Jonathan A. Duvall[1,2(✉)], Jonathan L. Pearlman[1,2],
and Hassan A. Karimi[3]

[1] Human Engineering Research Laboratory, Department of Veterans Affairs
Pittsburgh Healthcare System, Pittsburgh, PA 15206, USA
{jad75,jlp46}@pitt.edu
[2] Department of Rehabilitation Science and Technology,
University of Pittsburgh, Pittsburgh, PA 15260, USA
[3] Geoinformatics Laboratory, School of Information Sciences,
University of Pittsburgh, Pittsburgh, PA 15260, USA
hkarimi@pitt.edu

Abstract. Wayfinding is a common task routinely performed by people traveling between unfamiliar locations, but can be a challenge for people with disabilities. In order to be able to travel safely and comfortably, people with physical disabilities depend on the accessibility of the built environment. It is through these accessibility elements that people who use wheelchairs can find their ways in unfamiliar environments. When used by people with disabilities, wayfinding and navigation services must contain accessibility data and support functions to utilize this data. However, while there are standards, such as the Americans with Disabilities Act Accessibility Guidelines, upon which accessibility data can be based or derived, currently there is no automated metric for evaluating the level of accessibility for pathways. To fill this gap, this paper proposes a Route Accessibility Index as a metric for evaluating a pathway's accessibility and discusses its value in a wayfinding case study.

Keywords: Pathway · Sidewalk · Wayfinding · Accessibility · Disability

1 Introduction

The community participation and activity level of people with disabilities (PWDs) is impacted on by the accessibility of the routes they travel over. For instance, studies have shown that power wheelchair (WC) users travel 1.6 km on a normal day. However, in an active and highly accessible environment such as around convention centers and cities where they hold the National Veterans Wheelchair Games (NVWG), power WC users can travel up to almost 8 km per day [1]. A similar study of manual WC users revealed that on typical days they travel 2.0 km, and in a highly accessible setting, such as at the NVWG, they would travel an average of 6.5 km per day; one subject in this study travelled 19.4 km in one day [2].

The accessibility of the environment was one of the key factors that influenced the activity level and travel distances in the studies cited above. Accessibility of the built environment is guaranteed by the Architectural Barriers Act of 1968 (ABA) and the Americans with Disabilities Act of 1990 (ADA). The ABA ensures that buildings that are designed, built or altered by federal funding or leased by federal agencies are accessible to the public. The ADA greatly expanded the scope and details of the ABA outside of federally controlled environments. For example, the ADA states that "physical or mental disabilities in no way diminish a person's right to fully participate in all aspects of society." One purpose of the ADA is "to provide a clear and comprehensive national mandate for the elimination of discrimination against individuals with disabilities and to provide clear, strong, consistent, enforceable standards addressing discrimination against individuals with disabilities." [3] Title V of the ADA mandated that the Architectural and Transportation Barriers Compliance Board (Access Board) set up minimum guidelines "to ensure that buildings, facilities, rail passenger cars, and vehicles are accessible, in terms of architecture and design, transportation, and communication, to individuals with disabilities." [3].

The Access Board has established ADA Accessibility Guidelines (ADAAG) for Buildings and Facilities that give specific instructions and limitations about what is considered accessible. There are also many guidelines related to making pathways accessible, for example those by ADAAG (Table 1). The Access Board is currently updating their rules in an effort to make public rights-of-ways (PROW) more accessible for PWDs. These PROW rules will likely be accepted and promulgated and will formalize the rules on many surface characteristics including width, passing spaces, grade, cross slope, curb ramps and surface transitions. They are also looking to include requirements on surface roughness and rollability [4, 5].

Table 1. ADA guidelines

Parameter	Requirement
Clear width	Minimum 36 in
Openings	Maximum ½ in
Obstacle height	
≤ 1/4"	No bevel required
1/4"–1/2"	Must be beveled with Max 1:2 slope max
Ramps max slope	
1:12–1:16	Maximum 30 in high, 30 feet long
1:16–1:20	Maximum 30 in high, 40 feet long
Cross slope	Maximum 1:48

1.1 Monitoring ADAAG Compliance

Unlike roadways, municipalities do not have accurate inventories of the sidewalks locations, curb-cut locations, or information on sidewalk conditions. Consequently, it is unclear whether municipalities are compliant, or, by extension, accessible to PWDs. Some anecdotal information media sources suggest there is widespread non-compliance.

For instance, a recent survey of sidewalks in San Diego, CA indicated that they found 39,000 trip hazards with their survey only about half completed [6].

Many sidewalk surveys and repairs are conducted in response to complaints or incidents that have occurred, such as a trip or fall. Currently, most evaluations are conducted by a technician visiting the location where the complaint was reported, visually inspecting the area, measuring key details with a level and tape measure and taking a photograph. This process is slow and tedious for the technician. In order to make this process more automated and proactive, some automated tools to inventory and evaluate sidewalks have recently been developed [7–9].

Although the required data will exist as several discrete measurements (based on Table 1) along a sidewalk network, so long as it is geo-located (e.g., via GPS), it will afford more sophisticated calculation of route accessibility which can be defined as a cumulative measure of accessibility barriers along a selected route. For PWDs, route accessibility is more important than individual compliance measurements. This is because PWDs have different impairments that make one sidewalk compliance issue more or less impactful on mobility than another. A manual WC user, for instance, would likely be more affected by a non-compliant cross-slope than someone who ambulated but was blind or visually impaired, or even a power WC user. And the cumulative sum or percent of the selected route that has a non-compliance issue that makes it challenging for a certain person would be an important factor in determining which route that person should take.

Route accessibility is naturally tied to wayfinding by PWDs. Almost everyone is familiar with using a routing website or a GPS for traveling with a vehicle and it is expected that the roads on the route provided actually exist and are able to be driven over. This same expectation has not been realized yet for walking directions. Many of the same systems that give driving directions can give walking directions, but it is not uncommon for the sidewalks to be missing or for the condition of the sidewalk to be very poor, since these walking directions are typically based on the road network. Figure 1 shows an example of walking directions using Google Maps and Fig. 2 shows one segment of a route that Google Maps shows for walking directions. For ambulatory

Fig. 1. Example of Google Maps walking directions

Fig. 2. Image showing a possible pathway on Google Maps

people, this does not cause a big concern because they can typically navigate around obstacles. However, for PWDs, specifically WC users, having missing or inaccessible pathways can cause the person to have to backtrack which can cause a great deal of extra time and effort trying to navigate around the problem.

One solution to this problem would be a wayfinding system that could not only give directions, but could also give directions based on route accessibility. Attempts have been made to address this issue using crowdsourced reports [10, 11]. Neis measured the reliability of using volunteered geographic information in OpenStreetMap from WC users to identify characteristics of sidewalks in Bonn, Germany. This data was manually inputted from WC users and then used to identify the best routes for PWDs. For example, a user could specify that they only wanted to travel on surfaces that had inclines less than 5 %. However, one of the limitations identified in this study is the low accuracy and consistency of the data that is being provided by WC users.

This is a promising approach, but the main problem is that the data is not objective or standardized even within a group that has similar mobility abilities. What one person considers inaccessible might be accessible for someone else. This shows a need for more accurate, consistent, and objective data that can be analyzed in a customizable way rather than subjective data that is being self-reported by WC users. In this paper, objective surface characteristic data collected from a small neighborhood are discussed and an approach to determine the most accessible route is presented.

2 Data Collection

The data was collected for a small neighborhood using the Pathway Measuring Tool (PathMeT) [9]. Each segment of a sidewalk (i.e., curb cut to curb cut) was measured individually. The variables collected from this tool include a 2-D surface profile (height changes along a distance travelled), running slope, and cross slope. The profile can be used to determine height changes and roughness. The process for measuring roughness of pedestrian pathways is currently being developed as a standard with ASTM

International [12, 13]. The profile is recorded with approximately one mm resolution and the running slope and cross slope are recorded at 200 Hz. These variables were used in determining the Route Accessibility Index of each pathway. Because the surfaces on which data was collected were not connected, algorithms could not be used to find the shortest routes. Alternatively, three routes were chosen based on visualization of the map and considering small number of street crossings. The three routes that were analyzed are shown in Fig. 3 and combined together they had 24 different sidewalk segments.

The Route Accessibility Index for each surface was determined using Eq. 1 where d is the distance of the surface and the parameter values are maximum height change (HC), average running slope (RS), average cross slope (CS), and average Roughness (RO). Maximum rather than average level changes were used because level changes are not continuous for a surface like the other parameters.

$$\text{d} * [(\text{max HC/HC limit}) + (\text{Ave. CS})/(\text{CS limit}) + (\text{Ave.RS})/(\text{RS limit}) + (\text{Ave.RO})/(\text{RO limit})] \tag{1}$$

The parameter limits would be chosen by the individual that would be finding the most accessible route. In this paper, the limits were chosen to be 10 degrees for cross slope, 15 degrees for running slope, 50 mm for height changes, and 80 mm/m for Roughness.
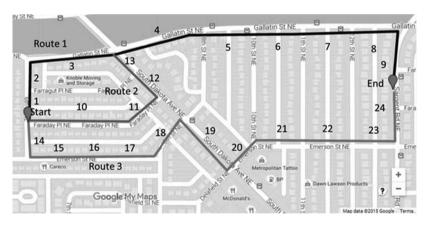

Fig. 3. Image showing three routes chosen for analysis

3   Route Accessibility Index

Table 2 shows the results of all of the pathway segments included in the three routes. For cross slope (CS), running slope (RS) and roughness, the average and maximum of values for each segment are given. For cross slope and running slope, the absolute values of the angles were used in order to have positive angles for both directions. This was done so that for a surface with equal parts of both uphill and downhill slopes, the average slope would not be zero, but would be the average angle away from zero.

Adding the Route Accessibility Indices of all of the segments for the three routes together gives total Route Accessibility Indices of 1086, 1271 and 1424 for routes 1, 2, and 3, respectively. Based on these results, the best route for the user to use would be route 1.

Table 2. Results of Route Accessibility Index analysis

Surface segment	D	CS Ave	CS Max	RS Ave	RS Max	Step Max	RO Max	RO Ave	Path no.	Route Accessibility Index
Units	M	deg	deg	deg	deg	mm	mm/m	mm/m		
1	56.4	2.0	6.3	3.6	8.3	9.9	91.8	45.7	1	68.3
2	49.6	2.5	4.4	5.2	8.1	14.3	98.1	49.4	1	74.5
3	165.0	2.7	7.9	5.9	10.2	9.4	97.4	40.6	1	223.1
4	153.9	2.0	5.9	3.3	7.5	11.5	81.4	39.5	1,2	176.4
5	82.8	2.4	7.8	3.1	5.9	12.2	97.8	47.1	1,2	106.1
6	82.4	2.5	5.4	2.7	5.9	7.2	59.8	43.3	1,2	91.9
7	80.4	1.9	4.7	6.2	8.9	10.3	73.3	40.0	1,2	104.8
8	86.0	3.2	5.9	6.6	11.1	11.9	75.3	51.2	1,2	140.4
9	85.8	1.7	7.7	6.1	8.1	6.6	69.9	36.6	1,2	100.1
10	197.5	3.1	6.9	1.2	4.0	31.7	89.0	43.4	2	310.2
11	69.1	3.9	8.8	2.3	9.3	17.2	96.3	52.8	2	107.1
12	53.5	4.1	6.1	4.1	6.4	13.7	64.9	43.2	2	80.0
13	51.6	2.3	4.4	4.0	6.2	2.9	59.0	39.6	2	54.0
14	53.0	3.2	6.3	1.2	4.6	62.2	85.3	64.0	3	129.4
15	128.9	4.3	9.8	3.4	7.5	21.8	150.1	59.5	3	237.1
16	30.0	2.4	9.3	1.0	4.6	7.8	60.9	50.2	3	33.0
17	70.2	2.3	7.4	1.6	12.1	43.1	76.0	44.3	3	123.4
18	80.6	2.6	5.5	2.5	6.3	21.5	95.4	36.4	3	105.8
19	114.5	2.7	4.6	3.6	12.5	88.9	100.3	37.2	3	315.3
20	41.1	2.4	7.2	1.8	3.9	8.7	124.3	45.7	3	45.5
21	87.0	2.2	5.6	3.1	7.0	13.5	110.9	44.1	3	108.6
22	81.1	2.2	4.4	3.8	9.5	7.4	101.6	66.9	3	118.0
23	71.9	2.5	5.0	4.6	11.0	12.8	83.5	56.8	3	109.4
24	85.8	1.9	4.4	5.5	7.2	8.3	52.6	33.7	3	97.9

4 Discussion

This article shows one way to determine a Route Accessibility Index that can be used as a wayfinding tool for PWDs. The proposed Route Accessibility Index, in its current version, includes cross slope, running slope, height changes, and roughness parameters. The parameters proposed all have to do with the characteristics of a particular pathway segment. The other parameters of a route that could be included, to determine the overall accessibility of a route, are segment width and those that affect the accessibility

of getting from one segment to another. Presence and characteristics of curb cuts could also be included to better understand how easy or possible it would be to travel from one route segment to the next. For a comprehensive discussion on the requirements and parameters of sidewalk networks suitable for wheelchair navigation, refer to Kasemsuppakorn and Karimi [14]. For people with visual impairments, the type and presence of crosswalk signals are very important.

Including the data for maximum cross slopes, running slopes, roughness, and height changes also allows a user to determine whether it is even possible to get past the recommended segments. For example, a segment could be very smooth and flat but have one 100 mm height change in the middle of the segment. In this case, the overall route accessibility of the segment could be lower than another route but it could be effectively impassable if the wheelchair user cannot get over that high of a step. This implies that the Route Accessibility Index could be personalized based on information about the pedestrian. Knowing the maximum values of these parameters could help reduce the number of candidate segments for analysis; one parameter's maximum value may make the segment impassable.

A prerequisite for the Route Accessibility Index is having large amounts of data for the potential routes that are being looked at. Currently very few, if any, cities have inventory data on their sidewalks and even fewer have any data of the characteristics of the sidewalks. The Pathway Measurement Tool [9], or similar techniques [7, 8], shows promise for collecting the data and calculating Route Accessibility Index and storing them in a database. However, manually collecting the required data takes a lot of time and resources. This is the main reason why collecting the required data through a crowdsourcing approach has become popular in recent years. As discussed in the introduction, one shortcoming of current crowdsourcing approaches is that the collected data is subjective and there are no agreed upon, specific parameters. Many approaches to collecting objective data using crowdsourcing are currently being developed. Karimi and Kasemsuppakorn have suggested that no single approach can automatically collect all sidewalk data and have proposed a hybrid of three approaches, namely image processing, road buffering, and crowdsourcing, to obtain complete and accurate sidewalk networks [15].

With a large database of data related to surface characteristics, cities and municipalities can take a proactive rather than reactive approach to repairing sidewalks by having a plan in place to repair inaccessible sidewalks before there are incidents or complaints. In this study the limits for the parameters were chosen as if a user had selected what they knew they could safely travel across. For cities, the same data can be considered and the ADAAG standards can be used to determine where the sidewalks are not accessible according to the guidelines.

5   Conclusion and Future Research

PWDs need to know accessible routes to navigate in unknown communities. Typical wayfinding services, such as Google Maps, do not provide suitable solutions for PWDs because their databases do not contain sidewalks, which means their directions are not based on sidewalks and sidewalk conditions are not available. An emerging alternative

to the conventional method of assisting in wayfinding and navigation is social network systems. Karimi, Dias, Pearlman, and Zimmerman have discussed the importance and methods of using social networks for sharing and exchanging wayfinding and navigation experiences among PWDs [16]. For another example of a personalized routing technique, based on fuzzy logic, for wheelchair navigation, see Kasemsuppakorn and Karimi [17].

Through a simple experimentation it was shown that the proposed Route Accessibility Index using parameters of sidewalks surfaces can determine the most theoretically accessible routes for PWDs to navigate in unknown areas. The parameters used in this study were cross slope, running slope, height changes, and roughness. Our future research includes improving the Route Accessibility Index as a metric for finding accessible routes by including other parameters such as segment width and those that are used in transition from one sidewalk segment to the next. We also plan to develop an algorithm that can automatically create a connected network of sidewalk segments using the collected data (performed manually in this work) in future.

Conflict of Interest. Two of the authors of this paper (Pearlman & Duvall) have equity in, and sit on the Scientific Advisory Board of a company that has licensed the PathMeT technology and evaluates and maps pedestrian pathways for accessibility.

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