Investigating User Risk Attitudes in Navigation Systems to Support People with Mobility Impairments

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ABSTRACT

This paper investigates the impact of visualizing the ***risk*** of encountering potential accessibility barriers on the route planning behaviour of pedestrians with mobility impairments. Using a prototype system, we explored the relationship between the risk of facing possible accessibility barriers and the navigation planning behaviour of the mobility impaired users. We found that mobility impaired users had a very strong inclination towards longer but accessible barrier-free routes instead of shorter potentially inaccessible routes (being willing to travel over 900 metres to avoid barriers), suggesting a degree of risk aversion that goes beyond the literature. However, we have also observed users' varying risk attitudes towards obstacles based on the type of impairments, mobility aids, and individual perceptions and mobility preferences. Our investigation underscores the importance of presenting risk information, which is currently overlooked in accessible navigation systems.

CCS CONCEPTS • Human-Centred Computing • Interaction design • Accessibility

Additional Keywords and Phrases: Urban Accessibility, Navigation Systems, Mobility Impairment, Risk Visualization.

1 INTRODUCTION AND BACKGROUND

Mobility is a vital requirement for leading an independent life [45]. Unfortunately, it remains a major difficulty for a broad range of people with disabilities [24], due to the present condition of the built environment, which contains a number of barriers. Mobility impaired people may need to rely on various forms of mobility aids (e.g., wheelchairs, sticks/cranes, crutches, guide dogs etc.) to navigate around urban areas, depending on the type of mobility impairment and the level of severity [8], [38]. Yet only few studies have actually focused on designing navigation technologies in the context of people with disabilities addressing their daily mobility challenges [15], [49].

An *'accessibility barrier'* is a feature of the built environment that makes it difficult or impossible for people with mobility impairments to reach their destinations while navigating in the built environment [38]. Mobility impaired pedestrians frequently encounter accessibility barriers such as stairs, bollards, missing dropped kerbs, steep slopes, rough surfaces, narrow sidewalks, cracked or broken sidewalks and public crowds in their daily lives [26], [40], [45]. Some of these obstacles can be anticipated and avoided if the wheelchair users receive ample information about the barriers to wheelchair access (especially before visiting an unfamiliar area), through an information system accommodating a broad user-base, which could satisfy varying individual perceptions and mobility needs along with the dynamic urban conditions [12], [26], [40].

The problem is that none of the existing navigation systems (e.g., Google Maps) including the specialist wheelchair routing systems like Routino and OpenRouteService, are presently capable of identifying these accessibility barriers to offer appropriate routes for mobility impaired pedestrians, mainly due to the unavailability of adequate geographical map data containing up-to-date wheelchair accessibility information [12], [18], [24], [29]-[31], [39], [40], [43]-[46]. Many studies proposed techniques in an attempt to improve the accuracy of OpenStreetMap data either by collecting input and feedback directly from mobility impaired users, [2], [3], [18], [27], [31], [43]-[45] by employing volunteers for data collection [16], or by tracking users' movement and location [22], [24], [44], [45]. However, little effort has been made yet to address how to manage the inevitable risk of imperfect accessibility information being provided to the users.

Since encountering undocumented accessibility barriers is nearly inevitable given the state of the built environment, disclosing the ***risk*** of finding possible obstacles or missing accessibility data, could provide users informed choices of whether to avoid the risk by taking alternative transportation modes, or at least prepare themselves (e.g., by starting their journey earlier, seeking guidance) if they are willing to take the suggested high-risk routes. Therefore, addressing these challenges is important to notify people with mobility impairments **in advance** about the ***risk*** of experiencing unwanted accessibility barriers in order facilitate route planning for mobility impaired pedestrians in the built environment as well as minimize their likelihood of serious accidents.

The contribution of this paper is an investigation of the impact of visualizing the ***risk*** of facing certain potential accessibility barriers **in advance** on the route planning behaviour of the mobility impaired pedestrians, using our proposed user interface prototype as a tool for data collection through a survey. The data analysis and result interpretations, followed by implications are discussed in sections 3 and 4 respectively. Our results illustrate the potential impact of visualizing the ***risk*** of obstacles on the navigation choices of the mobility impaired participants, based on their mobility aids and risk attitudes towards certain types of accessibility barriers in built environment.

2 METHODOLOGY

2.1 User Interface Prototype

The primary objective of this study was to explore the risk attitudes of mobility impaired people with regards to route planning as pedestrians, upon visualizing the ***risk*** of encountering certain potential accessibility barriers within the suggested routes **in advance**. Our user interface prototype (as demonstrated in **Figure 1**) was designed to display accessibility information including the ***risk*** of facing potential accessibility when planning a journey from 'A' to 'B', so that mobility impaired users can make informed decisions prior to initiating their trips. This would allow our target users to decide which route to select (e.g., the shortest route or a longer route with least accessibility barriers) or even switch to other transportation modes (e.g., public transport, taxi), based on their priorities and mobility preferences if they wish to travel as pedestrians with their mobility aids. Furthermore, the interface prototype was designed to be usable with keyboard commands to satisfy the WCAG 'Keyboard Accessible' accessibility guidelines [35], [36], [42] (as many participants had physical impairments that limit their ability to effectively operate a computer using traditional input devices, and it was important for this not to be a barrier in accessing our survey).

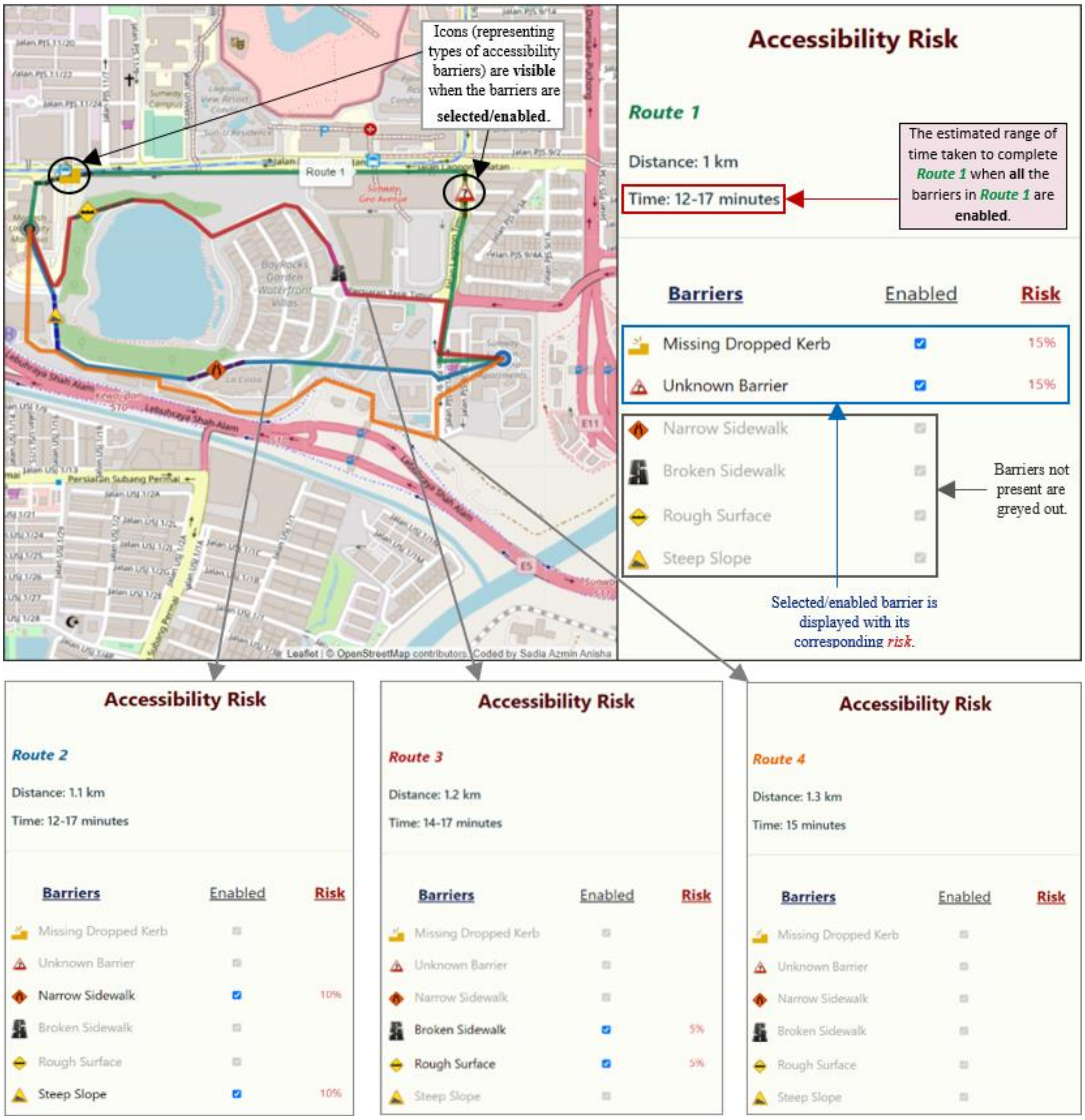

Figure 1: Accessibility Risk Information of Four Suggested Routes in **Scenario 1**

2.2 Study Design

This study is exploratory in nature. Our proposed visualization model for geospatial assistive technologies (GATs) was evaluated through an online survey containing both multiple choice (quantitative) and open-ended questions (qualitative). The survey was designed to investigate the route selection decisions that mobility impaired users took based on the route lengths and the risks of potential accessibility barriers presented within the demonstrated routes. This study was approved by our University Human Research Ethics Committee prior to conducting the survey.

The interactive map prototype was embedded in the survey questionnaire with 10 different scenarios (each with four routes) in order to allow participants to interact with the user interface while participating in the survey, so that they could simultaneously analyse the potential accessibility barriers within the given arbitrary routes (as demonstrated in the prototype) and select their preferred routes for each scenario if they were still willing to travel as pedestrians with their mobility aids (e.g., wheelchairs). If they entirely chose to abandon the suggested routes, they could also opt for other private/public transportation modes (e.g., car, taxi, ride-hailing apps such as Uber, Lyft, Grab) to reach their destination points safely and smoothly within an expected duration. For each scenario, the participants were required to provide the reason(s) for their choice, which is the qualitative part of the survey data, analyzed applying **thematic analysis.**

To maximize the recruitment of mobility impaired participants, target users were invited to participate in the survey via both email and social media platforms, which included relevant Facebook and LinkedIn groups. The survey was conducted for a month involving 20 participants with diverse age groups (25 to >55) from the UK, USA and Australia (demographics summarized in **Table *1***).

Table 1: Participant Demographics

Participant Identifier	Country	State/City	Age	Mobility Aid Type	Most Challenging Accessibility Barriers
P1	USA	Oviedo	25 - 34	Sticks/canes, Guide dogs, Rolling walker	Stairs, Missing dropped kerbs, Narrow sidewalk, Cracked/broken sidewalk
P2	England	Derby	34 - 44	Manual Wheelchair, Sticks/canes	Stairs, Missing dropped kerbs, Steep slope, Rough surface, Narrow sidewalk, Cracked/broken sidewalk
P3	USA	Dothan, AL	34 - 44	Electric Wheelchair, Sticks/canes	Missing dropped kerbs, Steep slope, Rough surface, Narrow sidewalk, Cracked/broken sidewalk
P4	USA	Fredericksb urg	18 - 24	Manual Wheelchair, Guide dogs	Stairs, Narrow sidewalk, Cracked/broken sidewalk
P5	UK	Telford	55 and above	Manual Wheelchair	Stairs, Steep slope, Barriers & gates across paths
P6	Wales	Pembroke	55 and above	Electric Wheelchair, Manual Wheelchair, Companion	Stairs, Bollards, Missing dropped kerbs, Steep slope, Rough surface, Narrow sidewalk, Cracked/broken sidewalk
P7	England	Leicester	34 - 44	Electric Wheelchair, Manual Wheelchair	Stairs, Bollards, Missing dropped kerbs, Rough surface, Cracked/broken sidewalk, Cars parked on paths
P8	Scotland	Dunfermlin e	25 - 34	Manual Wheelchair, Handcycle	Stairs, Bollards, Steep slope, Rough surface, Cracked/broken sidewalk, Cycling barriers
P9	England	Leicester	25 - 34	Manual Wheelchair	Stairs, Missing dropped kerbs, Steep slope, Rough surface, Narrow sidewalk, Cracked/broken sidewalk
P10	UK	Worcester	45 - 54	Electric Wheelchair, Manual Wheelchair	Stairs, Missing dropped kerbs, Steep slope, Rough surface, Narrow sidewalk
P11	UK	Lancashire	55 and above	Manual Wheelchair	Stairs, Bollards, Missing dropped kerbs, Steep slope, Rough surface, Narrow sidewalk, Cracked/broken sidewalk
P12	UK	Swansea	55 and above	Electric Wheelchair, Manual Wheelchair	Stairs, Missing dropped kerbs, Steep slope, Rough surface, Narrow sidewalk, Cracked/broken sidewalk
P13	Australia	Melbourne	34 - 44	Sticks/canes	Steep slope
P14	Scotland	Edinburgh	34 - 44	Manual Wheelchair	Stairs, Missing dropped kerbs, Steep slope, Rough surface, Narrow sidewalk, Cracked/broken sidewalk
P15	USA	Talladega	55 and above	Manual Wheelchair, Electric Scooter	Stairs, Bollards, Rough surface
P16	USA	Carlton	45 - 54	Electric Wheelchair, Manual Wheelchair	Stairs, Missing dropped kerbs, Rough surface, Narrow sidewalk, Cracked/broken sidewalk
P17	Australia	Melbourne	25 - 34	Manual Wheelchair, Mobility Scooter	Stairs, Bollards, Missing dropped kerbs, Steep slope, Rough surface, Narrow sidewalk, Cracked/broken sidewalk
P18	Australia	Melbourne	34 - 44	Electric Wheelchair, Manual Wheelchair	Stairs, Missing dropped kerbs, Steep slope, Rough surface, Cracked/broken sidewalk

P19	England	London	34 - 44	Walking Frame	Missing dropped kerbs, Steep slope, Rough surface, Narrow sidewalk, Cracked/broken sidewalk
P20	USA	San Jose, California	45 - 54	Manual Wheelchair, Sticks/canes, Rollator	Stairs, Missing dropped kerbs, Steep slope, Narrow sidewalk, Cracked/broken sidewalk

[1] This table shows important attributes of the selected participants which can influence their route preferences.

3 RESULTS AND INTERPRETATION

3.1 Quantitative Results

The results are presented in terms of examples from the survey. The quantitative results (summarized in **Table 2Error! Reference source not found.**) reveal that as the average number of barriers (i.e., ***risk** of facing each nominated barrier × number of barriers*) within each route increases, most participants tend to avoid all the suggested four routes – ***Route 1**, **Route 2**, **Route 3**, **Route 4***, and opt for other safer options (e.g., public/private transportations) in every scenario, particularly where all the four routes have two or more barriers, even if longer routes have fewer barriers or lower risk of barriers compared to the shorter routes. Apparently, 80% and 70% participants selected the longest route (***Route 4***) regardless of its distance in scenarios – see S1 and S9 respectively, where it had no potential barrier, only to avoid relatively low risks of facing a particular barrier in shorter routes.

Surprisingly, participants seem willing to even travel a significantly longer distance (i.e., 900 metres) further to bypass the risk of facing all the possible barriers. In S5, 30% participants chose the longest route (***Route 4***) which is 500 metres longer than the next shortest route (***Route 3***), having the risk of encountering only one barrier. Additionally, some respondents also selected shorter routes indicating that they might be indifferent to the accessibility barriers listed in those routes. Yet, in all the given scenarios, participants seemed most likely to ignore all the recommended routes with risky accessibility barriers and preferred other safer choices, unless a suggested route is barrier-free, because of their reluctance to compromise between lengthy routes with lower risk and shorter routes with high risk. In fact, 90% participants selected other alternatives in the last scenario (S10) where all the routes had some risk of facing six types of barriers, which means travelling additional 1 km through ***Route 4*** for the lowest possible risk (35%) might not be worth it. Otherwise, reasonably the longest distance they might be willing to travel, i.e., the distance ceiling is 3.7 km which is observed in S9. This exhibits that if accessible routes are available within a manageable distance for their mobility aids, then mobility impaired people would possibly proceed with the suggested routes rather than taking alternatives. Overall, our participants on average had a low risk appetite when encountering barriers, although there were the occasional exceptions.

Table 2: Summary of Quantitative Results

Scenario	Navigation Options	Distance (km)	Risk (%) of each Barrier ($\boldsymbol{Risk}_{barrier}$)	Number of Barriers	Average No. of Barriers ($\boldsymbol{Risk}_{barrier}$ $\times$ $Number\ of\ Barriers$)	Participants (%)
S1	Route 1	1 km	15%	2	0.3	0%
	Route 2	1.1 km	10%	2	0.2	5%
	Route 3	1.2 km	5%	2	0.1	10%
	Route 4	1.3 km	0%	2	0	80%
	Others	N/A	N/A	N/A	N/A	5%
S2	Route 1	1.5 km	50%	4	2.0	5%
	Route 2	1.75 km	58%	3	1.7	10%
	Route 3	2 km	50%	3	1.5	5%
	Route 4	2.25 km	63%	2	1.3	20%
	Others	N/A	N/A	N/A	N/A	60%
S3	Route 1	1.5 km	60%	3	1.8	15%

	Route 2	1.8 km	50%	3	1.5	10%
	Route 3	2.1 km	40%	3	1.2	10%
	Route 4	2.4 km	30%	3	0.9	0%
	Others	N/A	N/A	N/A	N/A	65%
S4	Route 1	1.5 km	60%	4	2.4	10%
	Route 2	1.9 km	50%	4	2.0	10%
	Route 3	2.3 km	40%	4	1.6	5%
	Route 4	2.7 km	30%	4	1.2	0%
	Others	N/A	N/A	N/A	N/A	75%
S5	Route 1	1.5 km	50%	4	2.0	10%
	Route 2	2 km	50%	3	1.5	15%
	Route 3	2.5 km	50%	2	1.0	5%
	Route 4	3 km	50%	1	0.5	30%
	Others	N/A	N/A	N/A	N/A	40%
S6	Route 1	1.2 km	60%	6	3.6	5%
	Route 2	1.8 km	50%	6	3.0	5%
	Route 3	2.4 km	40%	6	2.4	5%
	Route 4	3 km	30%	6	1.8	5%
	Others	N/A	N/A	N/A	N/A	80%
S7	Route 1	1 km	70%	6	4.2	5%
	Route 2	1.7 km	70%	5	3.5	10%
	Route 3	2.4 km	70%	4	2.8	10%
	Route 4	3 km	70%	3	2.1	10%
	Others	N/A	N/A	N/A	N/A	65%
S8	Route 1	1 km	80%	6	4.8	5%
	Route 2	1.8 km	80%	5	4.0	5%
	Route 3	2.6 km	80%	4	3.2	0%
	Route 4	3.4 km	80%	3	2.4	10%
	Others	N/A	N/A	N/A	N/A	80%
S9	Route 1	1 km	45%	6	2.7	0%
	Route 2	1.9 km	45%	4	1.8	5%
	Route 3	2.8 km	45%	2	0.9	10%
	Route 4	3.7 km	45%	0	0	70%
	Others	N/A	N/A	N/A	N/A	15%
S10	Route 1	1 km	85%	6	5.1	0%
	Route 2	2 km	68%	6	4.1	10%
	Route 3	3 km	52%	6	3.1	0%
	Route 4	4 km	35%	6	2.1	0%
	Others	N/A	N/A	N/A	N/A	90%

3.2 Qualitative Results

3.2.1 Low Risk Tolerance

The qualitative results which are mainly the reasons behind the navigation choices of the participants (*P1 – P20*), can further support the quantitative results (presented in 3.1). One of our key findings is the participants' willingness to take longer routes for avoiding moderate or low risks of facing any barrier as they would prefer barrier-free routes (reflected by S1 & S9).

In the first scenario (S1), a vast majority of participants chose the longest route (***Route 4***) because this route had no risk of encountering any potential barrier: *"I would rather take a longer route than a potentially inaccessible one."* (*P1*). This means that although the other three routes had only two potential accessibility barriers with very low risks, respondents would prefer to travel 300 metres further (compared to ***Route 1***) to completely avoid the possibility of facing any obstacle. Their key intention was to reach their destination within the expected time by ignoring trip interruptions resulting from potential obstacles: *"No known obstacles that could delay or stop me."* (*P10*). Specifically, avoiding all potential obstacles would possibly eliminate the journey time uncertainty and minimize the cost of re-routing (as explained by *P14*): *"It's the one with no hazards so the journey time will be most accurate. I'll use that much energy without needing to find more to change route or navigate"*.

A similar result was observed in S9 where a significant majority of respondents again selected ***Route 4*** because it also had no risk of barrier in this scenario. However, surprisingly, participants were willing to even travel additional an 900 metres through the longest possible route with no barrier, to avoid a moderate risk of only two potential accessibility barriers in ***Route 3*** so that they can travel independently with their mobility aid, as two participants explained *"It's a long route but safe for me to try on my own"* (*P9*) or as P18 put it, it is a *"long route but no obstacle for my wheelchair"* (*P18*).

In cases where all the four offered routes had more than one barrier, majority of the respondents decided to discard all the potentially inaccessible pathways with risky accessibility barriers, and preferred other safer options to avoid the risk of being stuck or delayed while passing through an unfamiliar area. The best examples represented S6 and S10 where almost all the participants opted for other public or private transportations (e.g., taxi, driving own car) to abandon all the four routes containing six same types of barriers with different risks in each route. In S6, ***Route 4*** has the lowest risk of facing each barrier type (30%), but since its distance is 600 metres longer than that of the next shortest route (***Route 3***), participants were reluctant to trade-off lengthy routes for a lower risk of facing obstacles: *"All routes are too steep for a wheelchair, but journey may be far enough for taxi…"* (*P9*). To be specific, even with low risks, participants were less willing to take a chance on longer routes with their mobility aids, and hence would take other transportation modes (e.g., taxi) instead. Similarly, in S10, participant *P14* specified the anticipated probability of re-routing due to the potential obstacles in an unfamiliar area to be the reason behind ignoring all the risky routes and opt for alternate transportation modes, as the severity of barriers are unknown, and hence it might not be worth the effort: *"Because there's hazards on all routes, I don't know the area to know how bad or what the hazard is, how bad the broken pavement is, how many stairs etc. so rather than waste energy it's the better option."*

In certain scenarios (e.g., S4, S8, S10), some respondents would also tend to avoid the routes containing specific type(s) of accessibility barrier that they might be susceptible to or concerned of such as steep slope: *"Each route has a steep hill"* (*P12* in S8), or an unknown barrier *"All routes had an unknown barrier"* (*P10* in S4), and/or narrow sidewalk: *"All routes had narrow sidewalk or unknown barrier risk % that were not worth risking"* (P9 in S10). This indicates that mobility impaired people are likely to avoid the routes containing the particular barriers they are vulnerable to.

3.2.2 Attempt to Minimize Pedestrian Trip Expenses

As indicated by *P14* in S9, trip expense can be a possible reason that may prevent mobility impaired pedestrians to take public or private transportations (e.g., taxi), especially if there is a barrier-free route even if it is significantly longer: *"It got no hazards and after all the journeys by taxi I'd be **broke** and in dire need of fresh air and exercise!"* As such, there is a minority group who take a different viewpoint from the majority in respect of their risk attitudes, due to practical reality.

Additionally, results from scenario S5 provide supplemental evidence of trip expense avoidance, where a significant proportion of the participants selected ***Route 4*** having only one barrier that was unknown, instead of taking other transportation modes. This implies that these participants were even willing to travel 500 metres longer than ***Route 3*** and take 50% risk with an unknown barrier since other routes had more obstacles, saying they *"would take a chance on the unknown compared to what was shown for the other routes."* (*P5*). This might be also because they think that only one barrier could be managed (as mentioned by *P1*): *"The unknown barrier could be easy to avoid/get help with."* – in other words, frequency is an important factor for them.

Another interesting response in S6, from participant *P10* who chose ***Route 4*** (600 metres longer than ***Route 3***) containing six potential barriers, indicates their readiness to travel additional 600 metres as pedestrians rather than spending money on other transportations (unless really necessary) because the barriers were manageable by their mobility aid and the risk was relatively low (30%): *"Manageable barriers in my electric chair, and the unknown barrier was only 30%, although if it was essential to get there on time, I would have taken car or taxi."* Similarly, this participant again chose ***Route 4*** containing three potential barriers with very high risk (80%) in S8, because the barriers listed in this route were manageable: *"although a high risk %, the barriers should have been manageable in electric wheelchair"*.

3.2.3 Willingness to Take Shorter Routes

In a number of cases, some participants have also expressed willingness to take high risk for shorter routes- ***Route 2***, ***Route 3*** or even ***Route 1***. For example, in S2, participant *P7* chose the second shortest path (***Route 2***) having a considerably high risk of encountering a steep slope because it was manageable by their electric wheelchair: *"Because my power chair should cope with the slope."* This is again supported by *P10* in S9, who chose ***Route 3*** having two potential barriers with moderate risk (45%) because the barriers were manageable, and it was 900 metres shorter than ***Route 4***: *"Barriers manageable and substantially shorter than route 4"*.

Some participants might be willing to take a certain level risk to travel shorter distances. For instance, in S2, participant *P8* selected ***Route 3*** containing three potential barriers each with a 50% risk, simply because of their ability to manage physical accessibility challenges with their mobility aids: *"Because it looks interesting and I'm not afraid of wheelchair challenges."* This participant even selected ***Route 1*** containing a considerably high risk of six potential barriers (60%) in S6, because it was the shortest route: *"Because it's most straightforward, looks most efficient route."*

Therefore, this implies that our target users can be disparately affected by different types of accessibility barriers based on the type of mobility aid and individual preferences. Whilst this is not surprising, it is important to consider the variety of concerns and risk attitudes, as well as recognize the heterogeneity within this population.

4 DISCUSSION AND CONCLUSION

In this paper, we have explored the risk attitudes of the mobility impaired users for the first time in the context of route planning by utilizing our proposed interactive map prototype. From our analysis, we observed a prominent impact of visualizing the risk of obstacles within given arbitrary routes on the routing behaviour of the mobility impaired people, which justifies the significance of our risk-based approach. Our findings imply that mobility impaired pedestrians prefer longer barrier-free routes over shorter routes with considerably low risk of facing fewer barriers, and thereby indicating substantial risk-averseness of mobility impaired people in general with regards to encountering accessibility barriers while navigating as most of them were sensitive to even low risks.

Nonetheless, one of our key interesting findings is that a considerable majority of participants have revealed willingness to even travel a significantly longer distance such as 900 metres further to bypass the risk of facing all the possible barriers in order to independently reach their destinations with their mobility aids within expected duration. This suggests that participants were still inclined to a barrier-free route even when the distance penalty of barrier avoidance (900 metres) is high, specifically a lot higher than the 500 metres distance gap used in the simulation paper by Tannert et al. (2019) presenting a similar finding [40]. Conversely, the perceived inconvenience concerning the cost of re-routing if a barrier is hit outweighs the actual risk of experiencing a barrier. However, this may vary amongst individuals with heterogenous risk attitudes towards different types of barriers who might be willing to choose shorter routes with higher risk of barriers because of being indifferent to the potential barriers present based on their mobility aids. For instance, an electric wheelchair user may not be concerned about steep slopes as much as a manual wheelchair user. A navigation system displaying a lower risk is therefore still useful for the group possessing low risk threshold.

Generally, addressing the risk of experiencing different types of accessibility barriers can distinctively affect the navigation behaviour of mobility impaired individuals depending on their type of the mobility aids determined by their nature of impairment, as well as their risk propensity along with their individual perspective regarding specific types of barriers [18]. This means that mobility impaired people can prepare beforehand by at least starting their journeys earlier, or seeking physical help from a caregiver, or even switching to other transportation modes (public/private) if required. In other words, people would at least know when to take a taxi, even though they can't afford it; and for those who can afford an alternative transportation mode, this would provide them with an informed choice.

Moreover, our approach can also help to alleviate the negative effect of incomplete geographic accessibility data by notifying target users in advance regarding the risk of potential unknown barriers of concern resulting from missing geodata, especially in the undocumented areas. Therefore, existing navigation systems (e.g., Google Maps) should consider incorporating potential **risk** features to improve its accessibility accuracy required for better route planning experience for the mobility impaired community, which in turn can enhance user satisfaction.

5 LIMITATIONS AND FUTURE WORK

Our study was restricted to people with motor impairments (mainly wheelchair users). This means our findings may not generalize to people with other type of impairments such as sensory impairments (e.g., visually impairments) or cognitive impairments (e.g., dementia), that can also hinder their navigation ability and may therefore possess dissimilar navigation behaviour as well as attitude towards our risk-based approach. An important limitation of this study was the limited number of relevant participants because of the difficulty recruiting relevant participants, as many people were reluctant to complete the survey. Consequently, our respondents were mostly based in relatively well-developed cities in regions like the UK, USA and Australia, since we could not target users from more diverse areas including less accessible developing cities, which could generate different results representing divergent risk propensity and navigation behaviour. Likewise, a city's level of documentation with reference to wheelchair accessibility can potentially affect the performance of our visualization model [40]. This means further work is needed to discover the risk attitudes of people with mobility impairments concerning urban navigation in other more (or less) accessible cities. In the future, we plan to extend our work by incorporating the frequency of potential barriers (e.g., the length of the barriers) to explore the variation in the navigation behaviour of mobility impaired users. Additionally, we hope to perform field experiments with more realistic scenarios and time constraints for better understanding of users' risk perception with respect to route planning.

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