Cartography M.Sc.

Master's Thesis

Why Do Route Planning Strategies of Machine Differ from Each Other and from Humans?

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2022

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Submitted for the academic degree of Master of Science (M.Sc.)
conducted at the TUM School of Engineering and Design,
Chair of Cartography & Visual Analytics
Technical University of Munich

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Date of submission: 07.09.2022

Statement of Authorship

Herewith I declare that I am the sole author of the submitted Master's thesis entitled:

'Why Do Route Planning Strategies of Machine Differ from Each Other and from Humans?'

I have fully referenced the ideas and work of others, whether published or unpublished. Literal or analogous citations are clearly marked as such.

Munich, 07.09.2022   Syed Miftah Zeya

Acknowledgements

Abstract

With the growing concern of climate change and deteriorating personal health, more and more government and non-governmental organisations are promoting and raising awareness for active accessibility, such as walking and biking. Various governments have separate budgets to improve the infrastructure promoting active accessibility. With the increasing use of mobile devices and different routing apps, we heavily rely on them for routing and navigation. Various mobile applications using different routing engines are available in the market, but human consideration for route planning is equally important. This thesis aims to investigate the differences between human-generated routes with machine-generated routes. It aims to find the priorities of machines when generating a route and compare them with the priorities of humans when planning the same route. The current most popular routing engines and technologies for pedestrian routing are compared with human preferences of route choices by conducting two online surveys with more than 60 participants in total. Since route choice preference is directly related to the travel scenario, this thesis considers three different scenarios which are most common in daily life. Google Maps (the most popular navigation app) and GraphHopper (an open-source routing engine) have been used for machine-generated routes. This research concludes by providing important findings and suggestions for route generation in a particular scenario. It also discusses some directions in which this research can be implemented.

Keywords: Active Accessibility, Routing engines, Navigation

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1   INTRODUCTION

1.1   Motivation and problem statement

In recent years, Pedestrian Navigation has come up as an important research topic in disciplines such as Cartography, Geographical Information Science, Spatial behaviour, Indoor and global positioning as well as neuroscience (Fang et al., 2015). Pedestrian Navigation is a fast-growing industry with significant market potential in the coming years. One of the reasons is the increasing use of GNSS enabled smart devices such as mobile phones, smartwatches, and various fitness trackers. With the emergence of advanced satellite navigation systems, we can expect a much better positional accuracy in the coming years, making navigation more precise. The increasing technology and a shift towards automatic and autonomous cars have created the need for more precise navigation and positioning systems. Space agencies are now aiming to create positioning systems which would be able to detect precisely which side of the street you are walking.

Walking and cycling are very enthusiastically promoted in developed countries. They offer very clear and demonstrated collective as well as individual benefits including health, climate change mitigation, pollution and noise reduction, reduced obesity and also some financial benefits. The more we are moving towards cycling and walking, the more we are relying on routing and navigation apps. Most of the bicycles and e-bikes you see on roads now come with a mobile phone holder to assist the user in routing. With the increasing use of mobile routing day by day, we will be requiring better and more efficient routing engines which should also have high user satisfaction. Almost all the new cities and towns under planning and development have their focus on pedestrian safety and walkability. Asian countries have also started including bike

and pedestrian lanes in new and old cities wherever possible. The capital of India, New Delhi, in June 2022, has announced that they will be building and renovating 500km of roads in the city with separate bike lanes. This could be a very good step for a city which has one of the worst air quality indices in the world. In a survey carried out by Wired (wired.com) in 2019, Copenhagen has been found to be the most bike-friendly city in the world. 62 percent of inhabitants go to work or school by bike. This justifies the spending of $45 per capita on bicycle infrastructure development and maintenance by the Danish government.

With the increasing use of mobile devices and different routing apps, we heavily rely on them for routing and navigation. Also, better and more efficient city planning is giving us more and more ways to travel from one place to another, thus making the decision-making complex. Almost constant walking speed throughout makes pedestrian navigation different from car navigation (Virtanen, 2011). GIS and GPS-enabled devices allow emerging professional practices that are focused on walkability audits (Shields et al., 2021).

As humans, we take many routes in our day-to-day lives that are purely based on our minds and thinking. We generally don't use navigation apps for routes or surroundings we are familiar with. All the mobile routing apps and companies insist that they provide the most optimum route in a given condition. But do they? Several questions remain. Maybe an optimum route for one user might not be the optimum for others. What makes machine-generated routes different from human-planned routes? Are they better? Should we always follow machine-generated routes? Figure 1 below shows the different routes suggested by two different routing apps for the same source-destination pair.
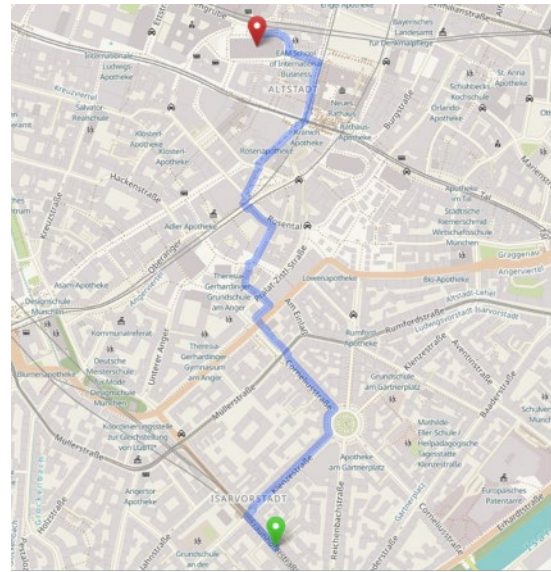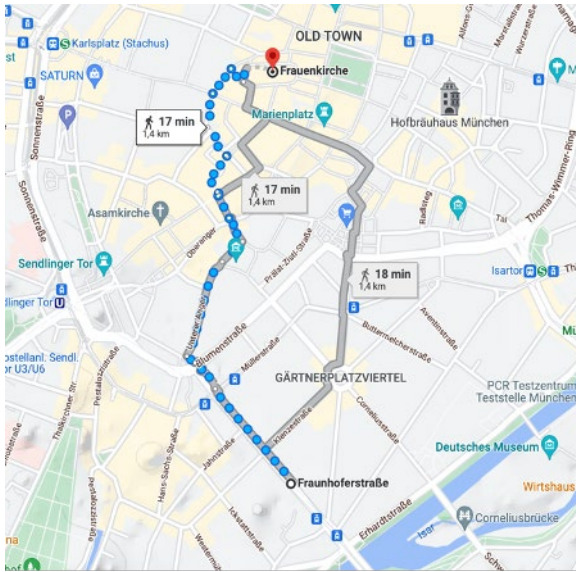
Figure 1: A screenshot from Google Maps showing the optimum walking route from Fraunhoferstrase to Frauenkirche (Left). A screenshot of OpenStreetMap showing the optimum walking route for the same start and end points (Right) at the same time of the day.

In this paper, we limit our analysis to accessibility by active travel. Different terms have been used in literature to communicate this concept, including pedestrian accessibility, walking accessibility, non-motorized accessibility, bicycle accessibility, walkability, and bikeability. In spite of the fact that non-motorized accessibility is in many cases used to designate walking and cycling, it is being replaced by human-powered transportation or active travel. This is on the grounds that these modes are related to the idea of physical activity, which as per the World Health Organisation is "any bodily movement produced by skeletal; muscles that requires energy expenditure", and includes walking, cycling and participating in sports. Subsequently, in accordance with these concepts we have adopted the term "active accessibility" to express accessibility by active travel, i.e., walking and cycling.

1.2   Research identification and research questions

1.2.1 Research objective

The main objective of this work is to develop a set of metric indicators that can evaluate routes calculated by different routing engines as well as by humans between the same source-destination pair. We want to know if or how the human route preference change with the change in scenarios or travel needs. Generally, it is assumed that people always consider a pleasant environment for walking, we want to investigate this assumption by conducting some research and surveys. This research doesn't aim to develop a new routing algorithm or a ready-to-use tool for pedestrian routing or city planners; it simply aims to better understand which factors humans consider when planning a route compared to machines.

In general, the study will include the following sub-objectives:

1. Analyse the routes suggested by two different apps under different scenarios.
2. Formulations of Metric Indicators to access the routes from both machines and humans.
3. Case study of routes generated based on human preferences under different scenarios to verify the feasibility of proposed indicators.
4. Which results should we follow?

The scope of this research is limited to pedestrian and bicycle paths due to time constraints. The driving mode is intentionally excluded to reduce complexity. Also, the real-time changes in surroundings and situations are not taken into consideration as they are temporary and can affect the final results.

The results of this research can be used in the field of data analysis and visualization mainly for understanding pedestrian routing behaviour. The final results will be valuable for city planners, cartographers, and GIS developers to make pedestrian routing more efficient by including and considering some of the metric indicators in

their web applications or city plans or maybe even in developing new routing algorithms.

1.2.2 Research Questions

Answering the following research questions and sub-questions will help to achieve the above-mentioned objectives.

1. Are the planned routes provided by dominant apps optimal? How are the optimal criteria defined here?

   a. Comparison of results from the two different routing apps to understand what factors they consider when deciding an optimum route.

   b. Do the apps always consider only "the shortest" route or "the fastest"?

2. Why do different apps provide different results? Considering our set of metric indicators, how similar are the routes from two different apps?

3. How will a human plan the same route under the same conditions? How different will it be from machine-generated routes?

   a. What factors do humans take into account while planning routes in different scenarios?

4. Which route should we follow in a given scenario?

1.3   Thesis structure

Chapter 1

The introduction chapter gives the introduction to the research direction of this thesis. It explains the motivation and problem behind this research alongside the contribution that this research can make to the field or cartography and Geo-information systems. The motivation and problem statement are followed by research objectives as well as the underlying research questions.

Chapter 2

This chapter discusses the theoretical background of this research idea and investigates the relevant literature and works from the past. This chapter presents in detail the relevant theories and previously developed methods and concepts that acted as a foundation of this research.

Chapter 3

The methodology chapter includes the research methods that have been used to answer the research questions for this study to meet the research objectives. After presenting the general research framework and metric indicators formulation, the user surveys are introduced and their purpose is explained in detail. This is followed by a subsection which discusses the online and offline platforms that have been used for the purpose of this research.

Chapter 4

The route choice survey chapter gives the details of data to be used and the study area where the research has been conducted. This is followed by first and second user surveys explained in detail with the details of the participants as well as the survey

questions. The chapter also explains the motives behind the questions that have been included in the surveys.

Chapter 5

The chapter results and discussion show and explain the findings of the first and second user surveys in detail. It also discusses the optional questions that were asked for more context about this research and for future work. This chapter aims to discuss the research questions of this thesis in general. It also investigates the results and findings of the two routing engines.

Chapter 6

Finally, the summary and outlook chapter presents the main research findings in a broader context. It also identifies the limitations of the study and recommendations for future work concerning theory or technical applications.

2 THEORETICAL BACKGROUND AND STATE OF THE ART

Investigation of route choice behaviour has its long history. Through many years of exploration, researchers have proposed both methods and theories to more readily understand the factors influencing in individuals' route choice. This chapter presents relevant theories and lately developed methods that acted as the foundation of this research.

2.1 Active Accessibility

Active travel, i.e., walking and cycling is very enthusiastically promoted in the western countries. These active travel modes have very demonstrated clear as well as collective benefits, which encompasses pollution, climate change mitigation, noise reduction, public health, obesity and individual as well as collective financial benefits (Vale et al., 2016). It is broadly perceived that active travel assists in reducing the negative impact of auto-dependent and physically inactive lifestyles such as air contamination, traffic congestion and medical conditions (Song et al., 2013). In the UK, local as well as national governments have attempted to encourage active travel in the last decades by constructing cyclists/pedestrian transport infrastructure and introducing proactive travel initiatives and will keep on supporting projects promoting active travel various schemes and funds such as the Local Sustainable Travel Fund (Song et al., 2013).

One of the manners by which active travel is promoted is by modifying the characteristics of the built environment where the people reside and move, as it has

been studied that built environment has a clear influence on travel behaviour and active travel in particular (Handy et al. 2002; Forsyth et al. 2008; Brownson et al. 2009). An important aspect of built environment is accessibility. Accessibility can be defined as ability to arrive at a relevant activities, individuals or opportunities which could require traveling to the place where those opportunities are located (Vale et al., 2016).

Walking and cycling are essential social activities and the cyclists and the pedestrians foster a specific relationship with the built environment (Vale et al., 2016). This converts into different attributes of the constructed environment such as feel, wellbeing and security, comfort and furthermore urban design qualities such as enclosure, imageability, human scale, complexity and transparency (Vale et al., 2016, Ewing and Handy 2009). The Figure 2 below shows the relationship between environment and active accessibility.
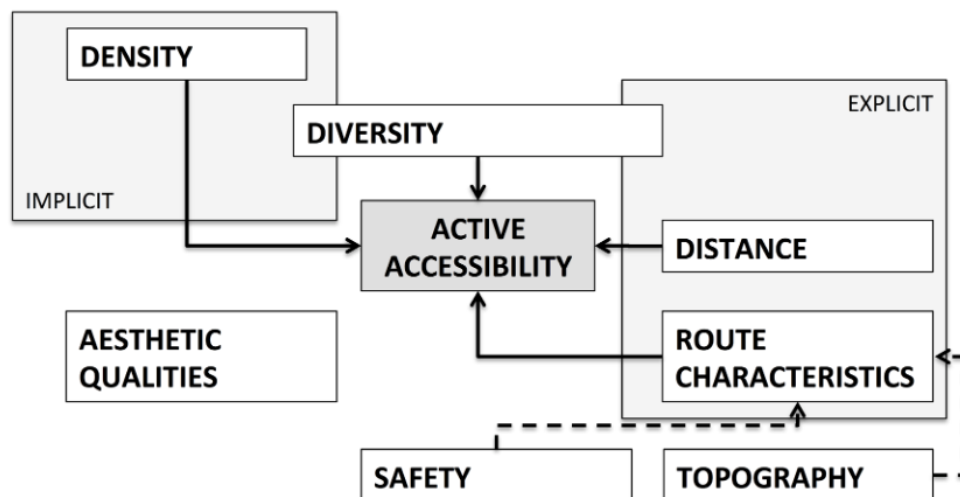
Figure 2: Relationship between built environment factors and active accessibility (Vale D, Saraiva M et al., 2016).

Active accessibility is either explicitly or implicitly included in the measurement of the built environment (Figure 2) (Vale et al., 2016). Practically speaking, density is frequently used as an implicit proxy for overall accessibility, as denser spots have more opportunities and facilities nearby. Similarly, the distance to the nearest facility is an explicit measurement of accessibility (Vale et al., 2016, Frank et al. 2006). In a very simple language, Active accessibility can be defined as the ability of a person to reach

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relevant activities by active travel alone. It tends to be either an individual based or place-based measure and the special needs of children, elderly people and disabled people can be taken into consideration (Dong et al., 2006, Kielar et al., 2015.).

2.2 Urban Mobility

According to The World Bank, Urban mobility was mainly about "moving people from one location to another location within or between urban areas". Due to increasing migration to urban areas (About 88% of the United States population is projected to move in urban areas by 2050) access to urban services is in high demand putting further strain on Public Transport systems. With the United Nations predicting that 68% of population will migrate to urban areas worldwide by 2050, it is vital to reshape urban mobility to combat the growing demand.

2.2.1 Why is urban mobility important?

Urban mobility, first and foremost is crucial to the proper functioning of our society. Urban mobility supports population growth, permitting increasing g communities to continue to access services in an efficient and timely manner (Liftango | Defining Urban Mobility, 2021).

According to Eltis (eltis.org), a Europe based urban mobility observatory, we need to think more about sustainable urban mobility plan which is "a strategic plan designed to satisfy the mobility need of people and businesses in cities and their surroundings for a better quality of life".

2.2.2 What is Microtransit?

In a very simple word, "Microtransit is dynamic routing". It taken into account your mobile smartphone applications and puts them to work to generate an efficient mode

of transport that adapts with each traveller. At the click of a button, you are able to book your trip that will consider fastest route for yourself. Microtransit fills the gap between personal vehicle ownership and public transport, creating an alternative means of travel that is adaptable, more affordable and has less negative impact on the environment (Liftango | What Is Microtransit? 2021).

2.3 Pedestrian route choice behaviour

Previous literatures have produced a good source of information on the route decision mechanism and how numerous factors produce and constrain the potential decision. Pedestrian routing depends more on landmarks than distances; Consequently, attributes of the route component must be intended to support meaningful routing and route description of all user group (Virtanen, 2011). Human navigation abilities rely upon the exactness of perceiving spatial information, the competence to generate spatial representation of the environment as well as the proficiency of using the spatial representations (Kielar et al., 2015).

Pereira (Borges et al., 2001) presented the term Behavioral Impedance (BI) which shows that pedestrian route choice can also be centered on criteria other than distance. For example, during a rainy day, pedestrian prefer covered/indoor routes. As pedestrian, we can walk almost everywhere, but vehicles are constrained by street network. Hence, pedestrian network development is rather challenging task. The following sub-sections discuss various factors that influence pedestrian route choice.

2.3.1 Pedestrian Route Network

Pedestrians normally use footpaths and pavements. Different components along the route are crossings, lifts, stairs, ramps, escalators, doors, underpasses and overpasses (Virtanen, 2011). For differently abled users, sills, kerbs, narrow passages, steep slope as well as level changes are barriers along the route (Borges et al., 2001).

In Finland, Finnish Transport Agency oversees public street data set Digiroad (Digiroad - Finnish National Road and Street Database - Finnish Transport Infrastructure Agency, 2022), which contains the spatial and the property information of the Finnish street and road organization. Below table shows the attribute of the footpath in the Digiroad. Attributes can be gathered using aerial images, other databases as well as cadastral maps. A field survey is necessary in some cases to complete the database (Table 1).

Footpath	Attribute value		
Width	Width in centimetres if value > 0		
Road side	Driveway direction related to digitalisation direction.		
	0	No road	
	1	Right side	
	2	Left side	
	3	Both sides	
Road id	Road identification number on database		
Separation from road	0	Nothing	
	1	Kerb	
	2	Railing/Fence/Other structure	
	3	Green wedge	
	4	Surface material difference	
	5	Painted stripe	
Surface material	0	Unknown	
	1	Hard artificial (e.g. tarmac, tile)	
	3	Soft artificial (e.g. sand, gravel)	
	4	Park path	
	5	Natural path	
Type	0	Unknown	
	1	Pedestrian only	
	2	Prom	
	5	Combined with bicycles	
	8	Combined with bicycles, pedestrians left side	
	9	Combined with bicycles, pedestrians right side	
	10	Cycles only	
Lights	0	Not defined	
	1	No	
	2	Yes	
Guiding rail	0	Not present	
	1	Present	
Place (Square)	0	Nothing	
	1	Place on left side	
	2	Place on right side	
	3	Place on both sides	
Overpass or underpass	0	Nothing	
	1	Underpass	
	2	Overpass	
Crossing road	Identification number of the crossing road		
Winter time maintenance	0	Not defined	
	1	Public	
	2	Private	
	3	No winter maintenance	
Accessibility class	0	Not defined	
	1	Accessible	
	2	Partially accessible	
	3	Not accessible	

Table 1: Attributes of the footpath (Digiroad - Finnish National Road and Street Database - Finnish Transport Infrastructure Agency, 2022).

2.3.2 Pedestrian routing patterns

As per a study carried out in 2010 (Risser et al., 2010), the fundamental characteristics associated with pedestrian routing patterns are the following:

1. A pedestrian requires very less room (0.5m2) when walking along a given path compared to various other modes of transport.

2. Walking speed is fairly slow and constant in comparison with other modes of transport.

3. Pedestrians are most vulnerable street users. Since they are not safeguarded by an armored vehicle, nor they wear any protective gear (i.e., helmet), they are exposed to various weather conditions such as sun and rain.

The relaxing quality related with walking influences route selection based on patterns that ensure a pleasurable experience, for example, a beautiful way in a new or aesthetically engaging environment. Pedestrian routes are characterized by walkability indicators which might influence the choice of route (Olaverri Monreal et al., 2016). A far-reaching overview is provided by (ZEC et al., 2018), where more than 150 indicators have been compiled from past works and thus arranged in groups. The variables that have an effect on route selection include, for instance, perspective that could indicate a positive feeling like the accessibility of stores, parks, retail outlets, public spaces, etc. and also aspects that might influence adversely like the presence of graffiti, dereliction and vandalism (Olaverri Monreal et al., 2016). There is no consistent opinion on how to group these indicators but (ZEC et al., 2018) has suggested that specific aspects are laid out such as comfort, connectivity, convenience, coexistence, etc.

2.3.3 What makes a street walkable?

A range of existing research have been considered when deciding on factors that make a street less or more walkable. Walkonomics (https://walkonomics.com) has taken

into account theses researches and combined the key factors into eight categories for their rating system. These eight broad categories are as follows:

Road Safety: It is a measure of how safe you feel on a specific street? It is determined by taking into account actual road accidents statistics, street type, speed limit and activities.

Sidewalks/Pavements: Does the street has sidewalk/pavements? How wide are they? Are they of good quality? Are they overcrowded? Are there unnecessary obstructions?

Easy to cross: How convenient is it to cross the street at regular points across it? It considers traffic movements on the street, physical obstruction, street width and availability of pedestrian crossings.

Hilliness: Is the street on a hill or it is flat? How steep is the steepest slope? In case the street is steep, are there any handrails or seats provided?

Navigation: How easily navigable is the street? Is it difficult to find your way around this street or the area? Is it obvious to get lost here? Are enough signs, street name or maps provide?

Fear of crime: How safe it feels to be on this street? It is determined by actual crime statistics (if available) and perceived crime as well as fear. Some other factors that are considered are vandalism, illumination and presence of cops.

Smart and beautiful: It gives the indication of cleanliness, amount of litter? How frequently it is cleaned? Does it have trees and other vegetation to make it look green? Conditions and attractiveness of the buildings?

Fun and relaxing: Is it an interesting and fun place to be? Does it have a relaxing atmosphere? Are there enough activities to do? Is it polluted, noisy or stressful? Would you like to spend your time here?

Walkonomics has also developed an interesting system that automatically rates the walkability of streets by interpreting public datasets is WalkoBot. Large number of roads in USA and UK have been rated by WalkoBot utilizing publicly available data.

2.4 Routing applications

Most of the pedestrian routing applications are based on information that is valuable for vehicle navigation systems, while the fundamental requirements of pedestrians are only occasionally considered (Borges et al., 2001). A few companies (for ex, Walkonomics), are beginning to consider pedestrian needs, for instance rating the walkability of the streets, yet at the same time most of the commercial navigation apps fail to integrate a comprehensive organization of route quality data in the user interface. Since the basic demands of pedestrians are rarely considered, there is an incredible potential for improvement in order to provide them with proper routing and navigation choices for an optimum user experience (Borges et al., 2001).

Routing application developed by Ari (Virtanen, 2011) for his own research is capable of creating different routes for visually impaired pedestrian, wheelchair users and other pedestrians. Since all these user groups have different routing preferences, for general pedestrians, route impedance calculation does not consider any attribute values; therefore, always suggests the shortest route. On the other hand, for the visually challenged and wheelchair users, defined set of attributes are taken into account leading to a different route which is not necessarily the shortest route. In fact, that routing applications operate in distributed information environment; it is nearly impossible to develop a database which contain all the information (Virtanen, 2011).

2.4.1 Algorithms commonly used in routing apps

The computation of routes in road networks has received enormous consideration from various research communities in the last decade and for majority of routing

applications efficient algorithm now exists. The main part of the work, nonetheless, centers around computing vehicle's driving direction; other scenarios, such as computing pedestrian routes have been neglected or simply excused as a trivial issue of applying a different cost function (Andreev et al., 2018). In this section we will discuss some of the most commonly used routing algorithms.

Dijkstra's Algorithm: The ability to find shortest route from one node to every other node within the same graph data structure makes Dijkstra's algorithm stands apart from the rest. This implies, that instead of simply finding the briefest way from start node to another specific node the algorithm attempts to find the shortest way to each and every reachable node - given the graph doesn't change. The algorithm keeps running until all the reachable nodes have been reached. Hence, you would just have to run the algorithm once and save the outcomes to be utilized over and over without re-running, except if the graph data structure changed in any way. The most common and widely used routing apps that uses Dijkstra's algorithm are Google Maps, Apple maps, Here and OpenStreetMap.

Bellman-Ford Algorithm: The Bellman-Ford algorithm works in a similar way as Dijkistra's algorithm to calculate the shortest route between starting node and all other nodes in the graph. One disadvantage of Bellman-Ford algorithm as compared to Dijkstra's algorithm is that former is slower and takes comparatively more time for computation; but it also has an advantage over Dijkstra's algorithm, which is, Bellman-Ford's capability to handle graphs in which some of the edge weights are negative (What Is the Best Shortest Path Algorithm? | MyRouteOnline, 2020.).

Floyd-Warshall Algorithm: What makes the Floyd-Warshall algorithm different from the above two algorithms is that is not a single source algorithm. Meaning, it computes the shortest possible distance between each and every pair of nodes as opposed to just calculating from the starting node (Bhatia Associate Professor, 2019). It works by splitting the main problem into shorter ones then combines the responses to solve the main problem. Since Floyd-Warshall algorithms calculates the shortest possible route

between all the relevant nodes, it would be of great use in when generating routes for multi-stop trips.

Most often, the choice of algorithm will depend upon the type of graph being used and the shortest route problem we are aiming to solve. For instance, for issues with negative weight edges, you would go to Bellman-Ford, though for sparse graph without negative edges, you would go to Dijkstra's algorithm.

2.5   State of the art and research problem

While the above sections describe the relevant theories and technologies about pedestrian routes choices and urban mobility, this section discusses the most relevant works related to walkability indicators. Walkability indices have effectively portrayed the walking environment in various urban communities, yet because of small samples and lack of data/information, many studies have not been successful to adequately analyse how households with fluctuating mobility needs as well as financial and time constraints maybe impacted by the walkability of their neighborhood (Manaugh & El-Geneidy, 2011). Moreover, a couple of studies have investigated varying measures of walkability on the same sample however have used one measure across trip purposes as well as socio-demographic types.

This points us to a direction that walkability measures are not "one size fits all" but vary greatly on trip purpose as well as financial capabilities of the residents. Walkability can thus be perceived as a "match between" inhabitants' desires and expectations of the destinations, their willingness to walk, and the quality of the required path. Neighborhoods that find this match between resident's needs and built form will probably have more people walking in them (Manaugh & El-Geneidy, 2011). Moreover, the value implication of walkability may be different for an individual who choose to walk because he lives in a walkable neighborhood compared to someone, who because of financial constraints has no choice but to walk. The walkability indexes developed by (Frank et al., 2005), has been utilized at different topographical scales,

census divisions, and network buffer around commercial centers or specific households.

A study in the UK carried out by (Song et al., 2013) in 2010 to collect study data used a postal survey using a questionnaire aimed to collect data on socioeconomic and demographic characteristics, travel behavior and neighborhood perception of the residents. This study area was about to get a major walking and cycling infrastructure upgrade and this research was carried out during spring and early summer to avoid major holidays season. For the sake of this study, five different journey scenarios were considered namely work, school, business, shopping and social activities. For each scenario, the respondents were asked to provide data for seven different travel modes namely walking, cycling, bus, train, driving, car as a passenger and other.

Borrowing insights from the above discussed studies and also considering their limitations, this thesis addresses the pedestrians as well as cyclists' route choice behavior and preferences in three different scenarios and also compares it with machine generated routes. A number of indicators have been identified and specified into these scenarios to examine their importance on human route choice. The details of the study will be described in the further chapters.

3 METHODS ADOPTED

In this chapter, the methods applied to address the research objective and research questions (mentioned in chapters 1.2.1 and 1.2.2) have been discussed. The development of this master thesis consists of three important phases – from understanding the basics of human route choices to understand user behavior (A), formulation of metric indicators (B), validation of these indicators by subsequent user studies (C). The aim of these phases is to help me in answering the research questions and to achieve the main research goal of this thesis. In each of the following sections the approach for answering the questions and the rationale behind the chosen approach is explained in detail.

3.1 The comparative study

In order to understand the role of human preferences in deciding a route for walking and cycling, reviewing the relevant literature was considered as a first approach. The rationale behind this approach is to find out how much work has been done in this direction and what are the findings, it also helps in understand the direction in which more work is needed. The detailed study of relevant literatures also helps to enrich this study with the valuable findings of the previous works. The selection and search for the literature was based on closely related areas of pedestrian routing, available routing algorithms, human route choice behavior and smart city planning. This paved the way to understand what are some important factors that are important in route planning and are also being used by city planners to plan walkable neighborhood. All these works helped in moving to our next section (chapter 3.2) about formulation of metric indicators.

3.2   Indicators formulation

The metric indicators are the most important element of this work. Three set of metric indicators have been developed for three different scenarios namely *Traveling to work place, Leisure walk,* and a *Bike trip on a weekend*. Each scenario has ten metric indicators (Table 2) which are considered to be influencing the user's decision to choose a route. Past articles and literatures have been used to develop our set of indicators. Also, before making a final decision, some of the participants were contacted about their opinion on it. Some changes have been made to the list of indicators depending on participant's feedback. The similar type of approach has been used by some local governments as well as private companies that deals with city planning and pedestrian routing. Some governments have also used this kind of methods (section 2.1 and 2.2) for developing cities that support active mobility.

N	Metric indicators	Traveling to work place	Leisure walk	Bike trip on a weekend
1	Type of the surface / wheelchair accessibility	✓	✓	✓
2	Total length of the route	✓	✓	✓
3	Number of turns / crossings	✓	✓	✓
4	Slope	✓	✓	✓
5	Air quality index / green area	✓	✓	✓
6	Noise level	✓	✓	✓
7	Amenities (benches, waste bins, public toilets, drinking water, shade, etc.)	✓	✓	✓
8	Estimated time of arrival	✓	✓	✓
9	Number of underpasses (underground crossings)	✓		
10	Sidewalk availability	✓	✓	
11	Illumination		✓	✓
12	Dedicated bike lane			✓

Table 2: Metric indicators for different scenarios used in this study.

3.3   User study and field survey

After the formulation of indicators, next step was conducting a user study to find out the user's order of preference for these indicators under the three gives scenarios. To conduct this user survey, a questionnaire (section 4.2.1) has been used which was self-explanatory and was sent out to 40-50 peoples to record their feedback on our set of metric indicators. The main purpose of this first user study was to determine if users find it useful and if it was okay to move ahead into the next step with the set of indicators we created. It was also kind of validation by users, we also gave the users a chance to put a free comment for every given scenario about their choices or preferences, also if they would like to add something which they consider important for their route choices but is not in our list of indicators.

Once all the survey response was received, they were analysed to know what are the most important factors that people consider when deciding an optimum route for themselves. Depending on the indicators that got the maximum votes for the given scenarios, they were given priority in our list of indicators. Based on this order of preferences a field survey was planned for each of the three scenarios in the city of Munich, Germany. The routes that were selected for the field survey were personally surveyed by me and all the required information were collected. In the next step, a second user survey (section 4.3.1) was created offering the participants three choices of route in each of the three scenarios. The purpose of this second survey was to validate the results that we obtained through first user study. So that the findings of this research can be generalized to a larger population and can tell us if the indicators that we came up with actually matters. In the both the user studies, a web-based survey was used to reach as many as participants.

3.4 Online and offline platforms used for this thesis

To address the research questions, a lot of data collection and analysis have to be done. The selection of the routing engine was also carefully considered. Since most of the users are relying on mobile devices for their route generation, it was decided to use the routing engines that can be used as a mobile app. Also, the idea was to consider a commercial engine and also an open- source product. Considering this, Google Maps (as a mobile application) and GraphHopper (https://www.graphhopper.com/) were used. Google Maps is the most used routing application in the world with a market share of about 65% and hence will be suitable for this study. GraphHopper on the other hand is based on the open-source concept and is used in many mobile and web applications.

For the manual data collection, GPX Tracker (a free app for IOS & android) is used. It has a very simple and easy-to-use interface. All the manual routes were recorded and exported as a .gpx file using this app.

For the post analysis and creating maps for the second user study and beyond, the open-source application QGIS was used. It also helped us to analyse the OSM data for our selected study areas. This approach helped to understand the details of the routes that were surveyed for this research.

4 ROUTE CHOICE SURVEY

This chapter describes and discusses the findings of the user surveys and related outcomes. The presented outcomes are derived from the qualitative and quantitative analysis of web-based user surveys. This chapter is further divided into 3 sections, Data and study area (section 4.1), first user study (section 4.2) and second user study (section 4.3). Consequently, each of the user study chapters have sub-sections (4.2.1 and 4.3.2) which discusses the content of these user surveys in detail.

4.1 Data and Study area

This section gives the details of study area and sources of data used for the purpose of this study. The study area for this thesis work is located in the city of Munich, Germany. There are three different locations depending on our research scenarios. These areas have been selected taking into account viable distance and alternatives in each case.

Scenario	Leisure walk
Start point	Drygalski-Allee, 81379 Munich 48.09945398, 11.50823486
End point	Fürstenried Palace, 81475 Munich 48.09426957, 11.48409976
Distance	3.32 km approx.
Time	30-40 min

Table 3: Scenario description; leisure walk.

Scenario	Office walk
Start point	Salzmesserstrasse 30, 81829 Munich 48.128294, 11.669236
End point	NXP Semiconductors, 81829 Munich 48.136913, 11.669449
Distance	1.35 km approx.
Time	15-18 min

Table 4: Scenario description; Office walk.

Scenario	Bike trip
Start point	Hatzelweg, 81476 Munich 48.086976, 11.498021
End point	Eichelgarten, 82061 Munich 48.049447,11.437527
Distance	6-7 km approx.
Time	25-35 min

Table 5: Scenario description; Bike trip.

The data related to this study was collected by commuting through these routes and also to know if there are any temporary issues that affect the routes. Fortunately, none of these routes were having any obstruction due to construction or any other type of temporary works. Also, the relevant street data was extracted from OSM database to enrich our analysis. These routes were selected by taking into account the findings of first user survey, so that they have the indicators that were needed for the second user survey.

4.2   First user study

The main focus of this survey was to investigate the following questions:

- What factors do people take into account when they plan a route for walking or cycling?
- Are the current routing engines taking those factors into account?
- How do the user's route choice preferences change in different scenarios? Do they always keep the same order of priority for their preferences?

This user study was very important to know the actual opinion of the people other than just using the factors mentioned in the literature. Different kinds of literature have been

developed in different parts of the world and they are influenced by local factors such as road safety, climate, air quality etc.

Secondly, the survey investigated how frequently the participants commute by various means in the city. When participants don't commute frequently within the city by foot or by bike, they will not be a very valuable contributor to our study. For all three scenarios namely *Leisure walk*, *Traveling to work place* and *Bike trip on a weekend*, the participants were given an open question (optional) to answer if they consider something that should also have been part of the survey. For the purpose of investigation or finding the user order of preferences, we gave ten possible metric indicators for each scenario (section 4.2.1) and asked the participants to order them as they would want it to. The following sections will discuss in detail about the questionnaire and the procedure used in making and distributing them. It will also describe the participants briefly. Finally, the findings of the survey from all the participants will be explained and analysed.

4.2.1 Survey questionnaire

The survey consisted of nine questions in total and was created using Microsoft forms. The web link of the survey was shared with people using social media such as WhatsApp, LinkedIn and Telegram.

The questionnaire was composed of four parts (see Appendix A). The first part was named as participants' details where information related to participants and their commuting behavior were recorded. These questions were related to the participant's age group, gender and commuting pattern. These questions were included to know what age group we are studying and how frequently they commute. The other three sections are the three different scenarios considered for this user study.

The next section was the scenario of *Travelling to work place*, where participants had to set their order of preference for the given indicators by dragging them up and down assuming that they walk to their office every day. The participants were provided with

ten metric indicators (created in section 3.2) for each scenario. For *Traveling to work place* scenario, the following indicators were provided:

Type of surface/wheelchair accessibility, number of turns/crossings, slope, AQI/green area, length of the route, amenities, noise level, estimated time of arrival, number of underpasses & sidewalk availability.

The next sections were the scenario of *Leisure walk* and a *Bike trip on weekend*. The questions were of similar types as first scenario (dragging up and down to set the order of preference), but there were a few changes in the metric indicators to accustomed them to the scenarios. For example, in case of bike trip, the dedicated bike lane was added as a metric indicator. Similarly, the illumination was added to the scenario of *Leisure walk* but not *Traveling to work place* because we normally don't go to office during the hours of darkness.

The second question in all the three scenarios was an open question about anything that a participant considers in his/her route planning but is not included in the list. This question was marked as optional because we don't want to force the participants to just fill something even if all their concerns were addressed in the previous question. This optional open question was provided for each of the three scenarios just to get an idea of what we are missing.

The average response time for the survey was recorded as eight minutes and thirty-four seconds. The full questionnaire is provided in the appendix A.

4.2.2 Survey participants

In total, 34 participants took part in the survey, where almost 50% commute on foot every day and more than 45% of them ride a bike a couple of times a week. More than 80% of the participants were in the age group 20-34 years (Figure 3 and Figure 4). Most of the participation was through WhatsApp groups and LinkedIn. A lot of people were also asked to participate through personal messages and mutual connections.
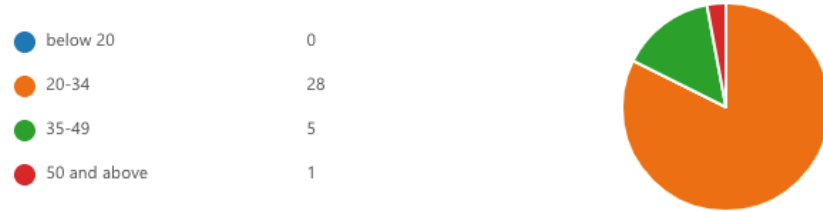
Figure 3: Age group distribution of participants of the first user study.

below 20	0
20-34	28
35-49	5
50 and above	1
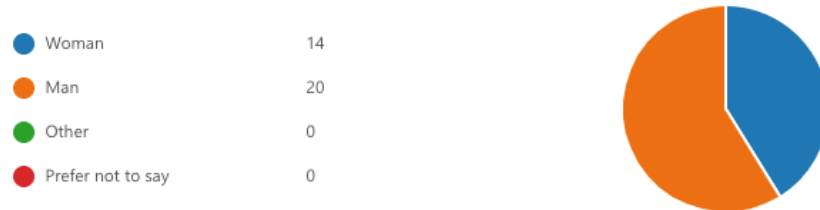
Figure 4: Gender distribution of participants of the first user study.

Woman	14
Man	20
Other	0
Prefer not to say	0

Moreover, some participants also answered the optional questions and suggested some things that they consider should be taken into account. About 25 responses were received for optional questions for different scenarios.

4.3   Second user study

The main focus of this survey was to examine the findings of the first user survey and to also check the relevance of the various metric indicators created for different scenarios during this study. In other words, this method was adopted to validate the metric indicators for their respective scenarios. For the purpose of this survey, three different routes were generated for each of the three scenarios (3x3, 9 routes in total). So, in each of the scenarios, the three different routes are from Google Maps, GraphHopper and a third route recorded manually using GPX navigator while walking through. The third route has been decided by taking into account findings from the first user survey. So, for each of the three scenarios, participants were given three different choices of routes to choose from.

4.3.1 Survey questionnaire

The survey consisted of nine questions in total and was created using Microsoft forms. The web link of the survey was shared with people using social media such as WhatsApp, LinkedIn and telegram. The questionnaire was composed of four parts as the first user study (see Appendix B). The first part was named as participants' details where information related to participants' age and gender were collected, also it had an open question to name three important factors that participants consider before deciding on a route. This question was asked before the participants see the factors that have been considered for the purpose of the second user study to get an unbiased answer which can help us to check if some factors which are mentioned by various participants but were not included in the survey. The remaining three sections are related to three research scenarios same as what was included in the first user study.

In each of the three scenarios, the participants were provided with three different routes to choose from which were generated by Google Maps, GraphHopper and manual route based on the results of the first survey. These routes were created as maps in QGIS to give all of them the same theme and to not let the participants know which route has been generated using which method. The reason for not disclosing the route generation method was to keep the participants unbiased about the routing engine in use and to guide them to consider the metric indicators as their differentiating factor rather than apps. This map was used as an attachment to the user survey. Some graphics were used to give an idea of the route and enhance the appearance. For every route, a table was provided giving information about the route to make participants better understand every route. These tables were based on the metric indicators that were created for the first user survey, and they list the metric indicators in the same order of preference as we received them during the first user survey. Some of the indicators were not easily quantifiable in numbers, so a different approach was used. For example, the 'Smoothness', 'Green area', 'Noise level' and 'Illumination' cannot be quantified in numbers. This problem was eliminated using the following measurement method:

Smoothness: Good, Average and Poor (1)

Good refers to a surface which is completely paved and smooth enough for wheelchairs and pushchairs.

Average refers to a surface which is paved but not very smooth and you would not like to walk on it with a wheelchair or a pushchair.

Poor refers to unpaved surfaces which can be hard to walk in case of rain and they have dust or gravel. The below images (Figure 8) show examples of surfaces that are considered good, average, and poor for the purpose of this study.

Figure 5: Examples of surfaces: good, average, and poor (from left to right).

Green area (2)

Expressed in percentage (%) and was calculated manually. Such as length of the route which has trees divided by total length of the route, multiplied by hundred to get a percentage. So if the total length of the route is 1500 meters and green area is about 400 – 450 meters then the route has been considered as 30% green. For the sake of minimizing errors, the percentages have been rounded off to the nearest multiple of five.

Noise level: High, medium and low (3)

High noise level refers to the two streets with general traffic flow around the clock. It includes major city roads.

Medium noise level refers to streets where traffic flow is low in off peak hours and heavy vehicles such as bus and trucks are prohibited such as one-way streets.

Low noise level refers to streets where motor vehicles are not permitted and only pedestrian and cyclists are allowed.

Illumination: High, medium and low (4)

High illumination refers to streets with lights on both sides of the road in a continuous pattern such as main streets with 4 traffic lanes.

Medium illumination refers to streets where lights are only on one side and not very close to one another such as narrow streets or one way.

Low illumination refers to streets with almost no lights or where are lights are highly separated from one another such as state highways and inner roads.

For the scenario *Travelling to work place*, a track of about 1400 meters was selected for the purpose of this research. The following Figure 5 shows the map that was generated for the scenario *Travelling to work place*. The tables shown in the below Figure 5, follow the order of preference obtained through first user survey for this scenario.

A		
1	Length	1.4 Km
2	ETA	17 min
3	Sidewalk	Yes
4	Smoothness	Good
5	Crossings	2
6	Green area	30 %
7	Trash bin	2
8	Bench	3

B		
1	Length	1.36 Km
2	ETA	17 min
3	Sidewalk	Partly
4	Smoothness	Average
5	Crossings	2
6	Green area	55 %
7	Trash bin	2
8	Bench	3

C		
1	Length	1.33 Km
2	ETA	15 min
3	Sidewalk	No
4	Smoothness	Poor
5	Crossings	1
6	Green area	80 %
7	Trash bin	3
8	Bench	4

Map legend: — — Track   Starting point   Trash bin   Bench   Green area   Destination

Figure 6: Route map created in QGIS for the second user study; scenario Traveling to work place.

The route A is derived using Google Maps and is the longest route amongst the three options and with the maximum time. It also has two crossings and sidewalk for the complete length of the route. The surface smoothness in best amongst the three options but has the least green area percentage. Participants were asked to choose one route that they would like to take in this scenario. This section also had an optional open question for participants to let us know why they have chosen or not chosen a particular route. We received 15 responses to this optional question. The route B is derived using GraphHopper and is a bit shorter than route A but has the same time as route A. It has better green area coverage compared to route A. The number of crossings, trash bins and benches are equal in both routes A and B. Route B has sidewalks only in some parts of the route and the smoothness is average. Route C is derived manually taking into account the order of metric indicator preferences from the first user study. Route C is the shortest and fastest route amongst the three options but has no sidewalk and poor surface. Though it has only one crossing and a maximum green area of about 80%. It also has the greatest number of trash bins and benches.

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For the scenario *Leisure walk,* a track of about 3000 meters was selected for the purpose of this study. The following Figure 6 shows the map that was generated for the scenario *Leisure walk*. The tables shown in the below Figure 6, follow the order of preference obtained through the first user survey for this scenario.
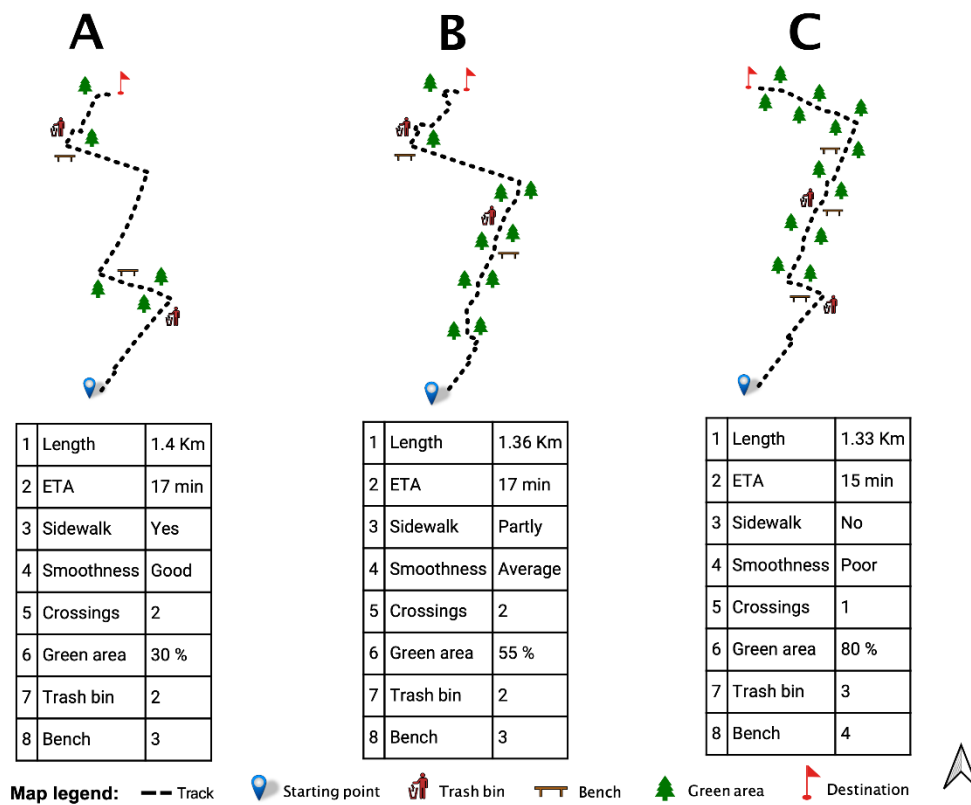
A   **B**   **C**

1	Green area	65 %
2	Noise level	Medium
3	Illumination	Medium
4	Length	2.97 Km
5	ETA	36 min
6	Benches	9
7	Trash bin	6
8	Smoothness	Good

1	Green Area	80%
2	Noise level	Low
3	Illumination	Medium
4	Length	3.22 Km
5	ETA	40 min
6	Benches	12
7	Trash bin	8
8	Smoothness	Average

1	Green Area	55%
2	Noise level	Medium
3	Illumination	Medium
4	Length	2.75 Km
5	ETA	38 min
6	Benches	8
7	Trash bin	6
8	Smoothness	Good

Map legend: ···· Track 📍Starting point 🚮 Trash bin ᴛᴛ Bench 🌲 Green area 🚩 Destination

Figure 7: Route map created in QGIS for the second user study; scenario Leisure walk.

The route A is derived using Google Maps and is the second longest route but with shortest travel time of just 36 minutes. The noise level and illumination are medium but the green area is second best amongst the three options with 65% coverage. The surface smoothness is best amongst the three options. It has nine benches and six trash bins. Route B is derived manually taking into account the user preferences from first user survey. It has the largest green area amongst three with about 80% coverage and has the lowest noise level. Though it has the maximum length and travel time amongst all three choices, it has largest number of bins and benches. The surface smoothness is not as good as other two options. Route C is derived using GraphHopper and has the second-best length and travel time amongst the three available options. It has the least green area with a coverage of about 55%. Noise level,

illumination and trash bins are the same as route A but has lowest number of benches. The surface smoothness is as good as route A. Participants were asked to choose one route that they would like to take in this scenario. This section also had an optional open question for participants to let us know why they have chosen or not chosen a particular route. We received 7 responses to this optional question.

For the scenario *Bike trip on a weekend,* a track of about 7000 meters was selected for the purpose of this study. The following Figure 7 shows the map that was generated for the scenario *Bike trip on a weekend*. The tables shown in below Figure 7, follow the order of preference obtained through the first user survey for this scenario.

A

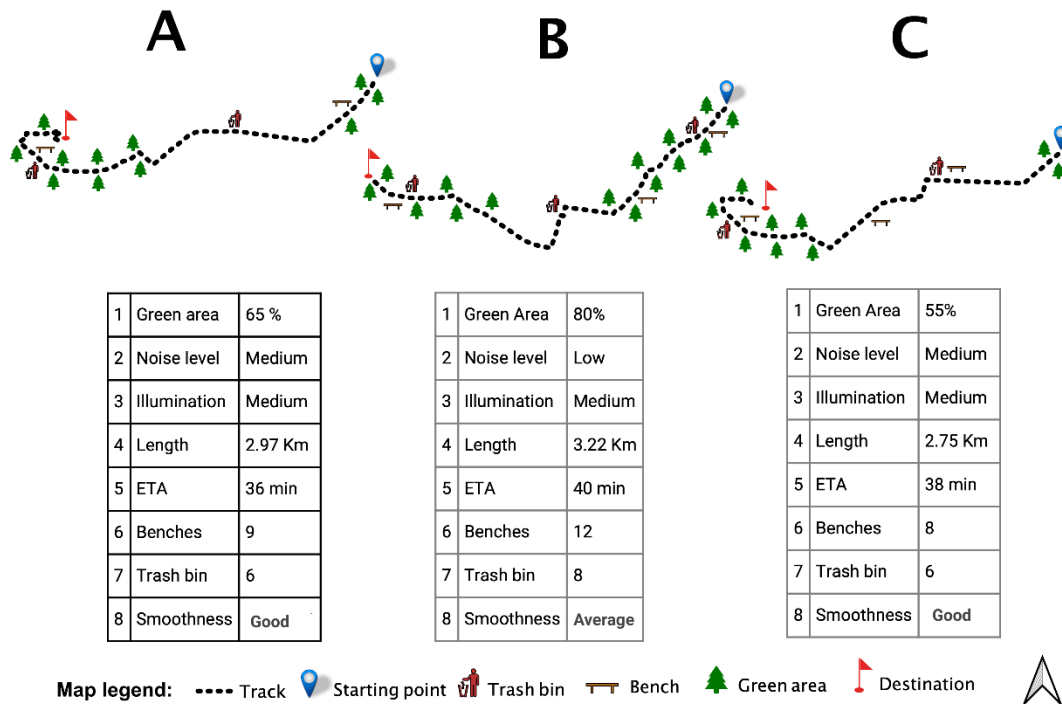| 1 | Length | 6.55 Km |
2	ETA	22 min
3	Bike lane	No
4	Green Area	25%
5	Illumination	Low
6	Noise level	Medium
7	Trash bin	3
8	Benches	4

B

1	Length	7.81 Km
2	ETA	32 min
3	Bike lane	Yes
4	Green Area	90%
5	Illumination	Low
6	Noise level	Low
7	Trash bin	4
8	Benches	6

C

1	Length	7.15 Km
2	ETA	28 min
3	Bike lane	No
4	Green Area	30%
5	Illumination	Low
6	Noise level	Medium
7	Trash bin	3
8	Benches	3

Map legend: – – Track   Starting point   Trash bin   Bench   Green area   Destination
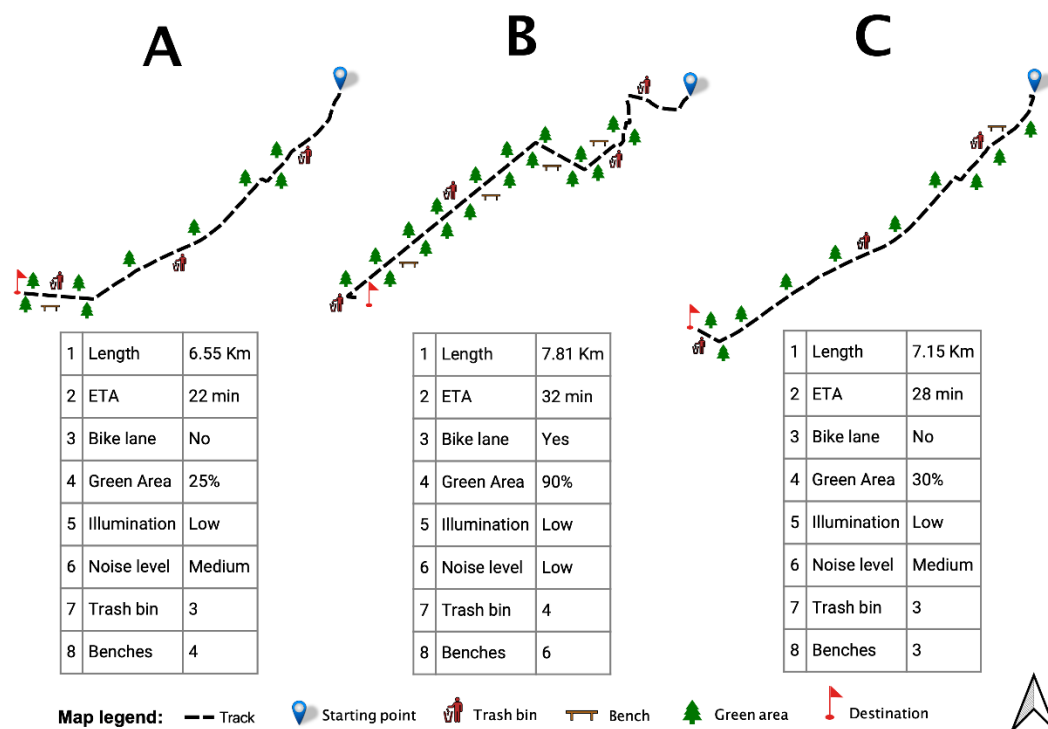
Figure 8: Route map created in QGIS for the second user study; scenario Bike trip on a weekend.

Route A is generated using Google Maps and is the shortest and fastest route amongst all three options with a length of about 6 500 meters and a travel time of just 22 minutes. It has the least green area with a coverage of only about 25% and has no bike lanes. The illumination is low as the other two options but the noise level is medium. It has three trash bins and four benches. Route B is derived manually taking into account user preferences from the first user survey. It is the longest route with

maximum travel time of 32 minutes amongst all the three options for this scenario. It has an edge over other two routes in having a bike lane and has the largest green area coverage of about 90%. The illumination is low same as the other two options but route B has a low noise level amongst all the options. It has four trash bins and six benches. Route C is generated using GraphHopper and has medium travel time and length of about 28 minutes and 7015 meters respectively. Unfortunately, it has no bike lanes and the green area coverage is only about 30%. The noise level is medium and the illumination is low. It has three trash bins and three benches. This section also had an optional open question for participants to let us know why they have chosen or not chosen a particular route. We received 8 responses to this optional question.

All the tracks selected for the purpose of this second user study were chosen on the basis of their fitness with respect to our metric indicators used in the first user survey. The average response time for the survey was recorded as eight minutes and seventeen seconds. The full questionnaire is provided in the appendix B.

4.3.2 Survey participants

In total, 28 participants took part in the survey, where almost 70% were among the age group of 20-34 years and almost equal number of participants. More than 80% of the participants were in the age group 20-34 years. Most of the participation was through WhatsApp groups and LinkedIn. A lot of people were also asked to participate through personal messages and mutual connections. The second user survey was sent to at least 40% new participants in comparison with first user survey to keep the results less biased and as much generalizable as possible.

Moreover, some participants also answered the optional questions and shared their opinion on why they have selected or not selected a particular route in a given scenario. About 28 responses were received for optional questions for the first scenario *Travelling to work place*, 15 responses for the scenario *Leisure walk* and seven responses for the scenario *Bike trip on a weekend*. Figure 9 and Figure 10 below provide an overview of the participants in the second user survey.
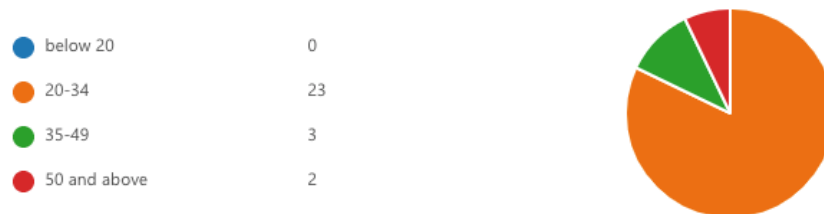

Figure 9: Age group distribution of participants of the second user study.
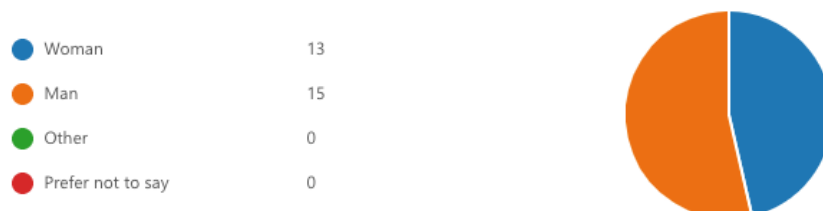
Figure 10: Gender distribution of participants of the second user study.

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5 RESULTS AND DISCUSSION

This chapter discusses the findings of both user surveys in detail. This chapter has three subsections which are User study 1 (section 5.1), User study 2 (section 5.2), and Analysis of machine-generated routes (section 5.3). In sections 5.1 and 5.2, each of the three different scenarios has been discussed in a separate paragraph to make it easier to understand. The last section 5.3 discusses the two different routing engines and their findings used for this research.

5.1 First User study

The results of this first user study are explained in this section as per the three different scenarios. Firstly, for the scenario of *Traveling to work place*, the indicator 'total length of the route' dominated the results and about 50% of the participants choose this as their first preference followed by 'estimated time of arrival' which was chosen as a most popular second preference by more than 45% participants. 'Sidewalk availability' was the most popular third choice by more than 30% of participants. Some of the indicators got a mixed response and were not having a prominent place in the order of preference. The indicator 'type of surface' became the most popular choice for the last position in our survey securing about 28% of the vote for the last position. While 'number of underpasses' appeared as the second last choice with about 30% votes for the ninth position. Figure 11 below shows the overview of the outcome of the survey for the scenario, *Traveling to work place*.
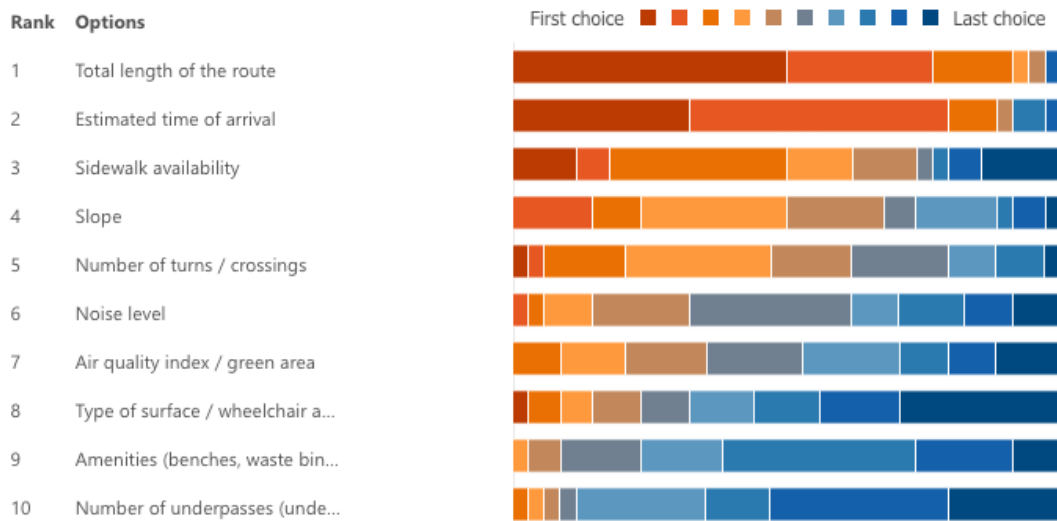
Figure 11: User preferences of metric indicators received in the first user study; scenario Traveling to work place.

These results showed a pattern which was expected in this scenario considering human behavior as most people will not leave their houses early to enjoy the route while travelling to office. So, the preference in most cases would be the length of the route and travel time. Some participants also mentioned that for them weather effects on the route and familiarity are of importance.

Secondly, for the scenario *Leisure walk*, the indicator 'Air quality index/Green area' dominated the survey with about 35% of participants voted it as their first choice followed by 'Noise level' which has been voted as most popular second choice by about 23% participants. For the third choice 'Amenities' appeared to be the most popular choice by securing about 23% votes. In this scenario, the last two preferences have been 'Total length of the route' and 'Type of surface/wheelchair accessibility' which emerged as most popular tenth and ninth preferences respectively. The Figure 12 below shows the overview of the outcome of the survey for the scenario *Leisure walk*. The finding of the first user survey for this scenario was also not very unexpected, but some participants mentioned that they would also consider walking in place or street which is less crowdy.

Rank	Options	First choice ▮▮▮▮▮▮▮▮▮▮ Last choice
1	Air quality index / green area	
2	Sidewalk availability	
3	Noise level	
4	Amenities (benches, waste bin...	
5	Slope	
6	Illumination	
7	Estimated time of arrival	
8	Total length of the route	
9	Number of turns / crossings	
10	Type of surface / wheelchair a...	
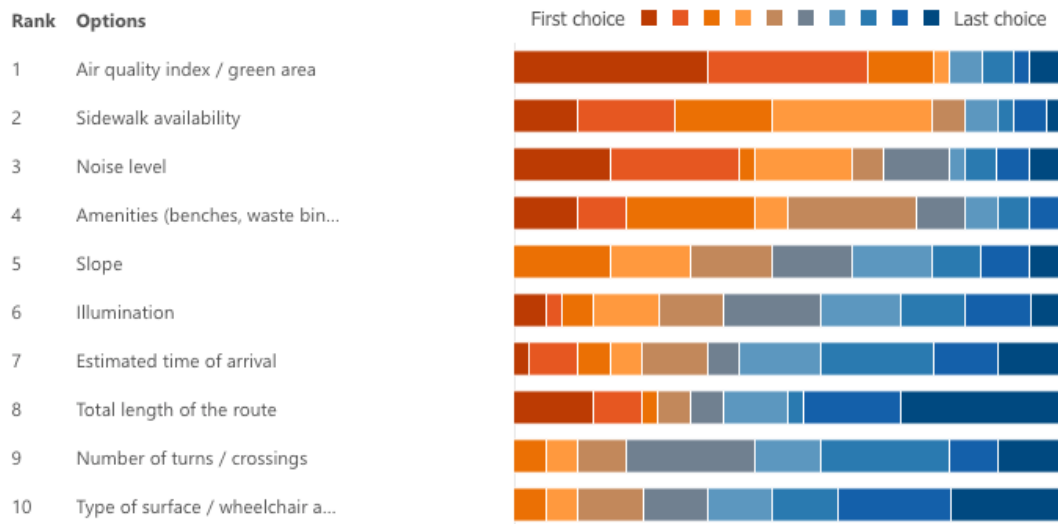
Figure 12: User preferences of metric indicators received in the first user study; scenario Leisure walk.

For the third scenario *Bike trip on a weekend*, 'dedicated bike lane' has been the most popular first choice (getting 47% votes) amongst all ten indicators. Followed by 'Type of surface' which appeared to be most popular second choice by about 24% participants. The third position in this category is 'Green area' which received more than 20% votes for most popular third choice. Subsequently 'Illumination' and 'Amenities' got the ninth and tenth position respectively by securing about 30% and 40% votes. The Figure 13 below shows the overview of the survey results for the scenario Bike trip on a weekend. In this scenario, the result was a bit surprising as dedicated bike lane got the first position, because slope or difficulty level is also considered an important factor for a bike trip. Some participants also mentioned that the purpose of bike trip makes an impact on their route preference such as relaxation, sightseeing, calmness etc. Some also mentioned that they would not prefer riding on a motorway but on residential streets.
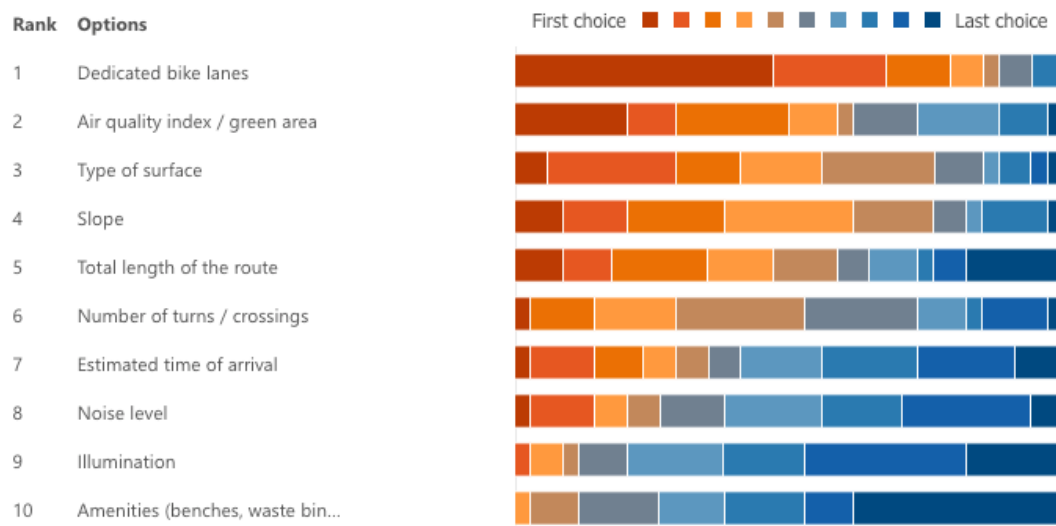
Figure 13: User preferences of metric indicators received in the first user study; scenario Bike trip on a weekend.

As we can see from our results, people's choice or order of preference changes with respect to scenarios; such as 'Length of the route' appeared as the most popular first preference in the scenario *Traveling to work place*, whereas 'Green area' appeared first preference in case of *Leisure walk* scenario. Similarly, dedicated bike lane appeared as the most people first preference for a *Bike trip on a weekend*. All these findings were carefully analysed, and were used in second user survey as a reference to generate manual routes based on human preferences.

5.2   Second User study

This section discusses in detail the outcome of the second user survey. In the first scenario *Travelling to work place*, the outcome is not very one sided. As 46% participants considered route A as their preferred choice while route B was considered first choice by about 25% participants and route C was considered first choice by about 29% participants. As mentioned in the previous section (4.3.1), route A was generated using Google Maps, while B was generated using GraphHopper and route C was generated manually. Figure 12 below represents the users' preference of route choice (A, B, C) for this scenario.

Figure 14: Route preferences in second user study; scenario Traveling to work place.

This result contradicts the initial hypothesis which was the basis of the formulation of our metric indicators. It also contradicts the findings of first user survey which gave 'length of the route' 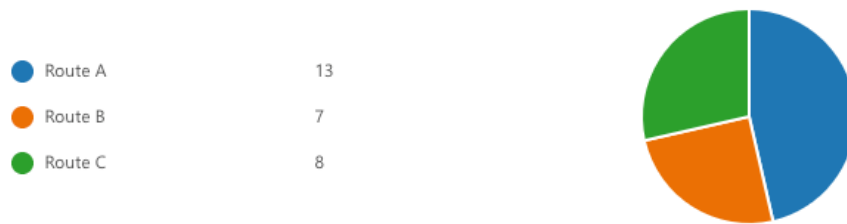and 'estimated time of arrival' first and second position in the order of preference respectively. The type of surface appeared to be the least important indicator in the first user survey for route planning in the scenario *Travelling to work place*. But in the second user survey, route A emerged as the most popular choice even though it was not the shortest and fastest amongst the three options. It is very interesting to know that most of the participants considered type of surface as an important factor for all weather routing. Some participants also mentioned that since the estimated time of arrival difference is not considerably large, they have not considered it a deciding factor in this case. Some participants also considered sidewalk as an important and deciding factor in this case. This approves our finding and estimations from the first user survey, where sidewalk availability was most popular third choice. The people who voted for route B as their preferred choice consider that route B is a good compromise amongst the three available choices as it has more green area whereas length and travel time are not significantly different. The participants who voted for route C present their arguments that for them the deciding factor is green area as it would give them a pleasant and calm feeling before and after a tiring workday. Some participants also mentioned that even though route C has no sidewalk and good surface, it has the least travel time which gives a sense that it has little or no traffic and road noise. Some participants also mentioned that a route with a lot of green area and good surface smoothness will be their ideal path. At the end we can say that as per our study and findings, Google Maps might be a better choice if you want to plan a route to your workplace. As mentioned in last paragraph, most people would not like to leave their house early and arrive home late to and from office

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just to enjoy the route. Since the route generated manually based on user preferences from first the user survey as well as using GraphHopper got almost similar number of votes, it could be interesting to see how the pattern remains if the number of participants would increase. Also, an important observation could be that people really don't care about amenities along the way when walking to work place, but they would like to consider supermarkets as well as eateries if there is a possibility along a route.

In the second scenario *Leisure walk*, the results are completely one sided and clear (Figure 15). Route B was selected by 93% participants as their ideal choice. While route B was only selected by 7% participants and route C was selected by none of them. As mentioned in the previous section (4.3.1), route A was generated using Google Maps, while B was generated manually and route C was generated using GraphHopper.

● Route A	2
● Route B	26
● Route C	0

Figure 15: Route preferences in second user study; scenario Leisure walk.

In this *Leisure walk* scenario, the results obtained by the second user survey support the findings of first user survey and they also confirm the hypothesis that distance and travel time are not very important in a *Leisure walk* scenario that was used as a base in developing the metric indicators for this scenario. Some participants also mentioned that low noise level is of utmost importance to them when considering a route for *Leisure walk*, which is also in line with the first user survey findings where 'Noise level' was voted as most popular second preference. Few participants also mentioned that for *Leisure walk*, distance really don't matter so much. So, for the *Leisure walk* scenario, route B is the clear winner even though it is the longest route and not the best surface smoothness. The participants who selected route A didn't really mention why they choose it over the other two options. As mentioned earlier, route C got no votes. It is worth to note how people's route priority changes depending on the travel scenarios.

If we compare the last two scenarios, the metric indicators such as type of surface moved down in the order of priority in the *Leisure walk* scenario compared to *Travelling to work place*. A reason behind this could also be the dressing patterns of the individuals, for example, we usually go to offices in a more formal dressings and shoes than when we go for a leisure walk. Hence, if you are wearing a running or jogging shoes, type of surface might not make a lot of discomfort as it could make with formal shoes. Important thing to note here is none the not both the routing algorithm took this into consideration. At the end, we can conclude that for a *Leisure walk* scenario, based on the user input that we received; it is not a good idea to use a machine generated route. As both the routing engines that we used, show walking as a mode of transport, but they don't consider the walking scenario and hence try to calculate the shortest or the fastest route. A. very interesting finding form this scenario is that the manually generated route was shorter and faster than the routes suggested by routing engines. This can point us in a direction that routing engines do not always follow the shortest or fastest route.

In the third scenario *Bike trip on a weekend*, route B is a clear winner with about 93% participants considering it as their choice (Figure 16). In this scenario route A was generated using Google Maps, route B was generated manually based on user preferences from the first user study, and the route C was generated using GraphHopper. Route A and route C have a tie with 4% votes each. Even though the route B is the longest route with largest travel time, it has been voted as first choice. Most of the participants who considered route B as their ideal choice mentioned that dedicated bike lane, green area and low noise level are the most important indicators for them which validates the findings of first user survey where 'dedicated bike lanes' and 'green area' appeared to be the most popular first and second preference respectively. But the 'noise level' which was classified as most popular choice for eighth or ninth position in the first user survey appeared to be amongst the most important indicator in the second user survey, and hence contradicts the findings of first user survey for this given scenario. Some participants also considered dedicated bike lanes as an important safety feature for the selection of the route. The participants who voted for route A and route C in this scenario did not mention the reason for their

answer. Considering the user preferences for this scenario, we can say that both the routing algorithms performed equally poor. None of them considered the dedicated bike lane in their route suggestions. Hence, we can conclude that in a scenario of bike trip, it would be good to try another routing algorithms or follow the local guides.

🔵 Route A	1
🟠 Route B	26
🟢 Route C	1
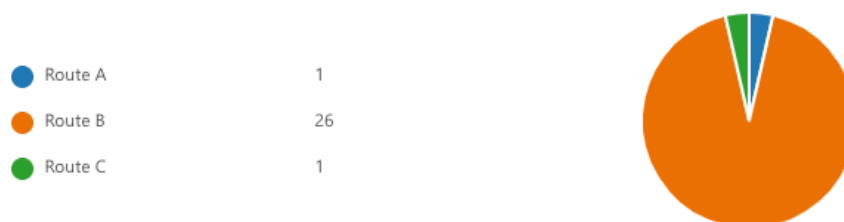
Figure 16: Route preferences in second user study; scenario Bike trip on a weekend.

We also received some responses to our open question in the first section of second user survey. Some of the interesting responses that we received and those who were not part of our study are sense of security (which also depends on your familiarity with the surrounding), weather, elevation, shadow during summer time, low speed zones, available landmarks etc. Some participants also mentioned that during travelling to work place they could also consider route which has a supermarket or food shops, which seems very relevant as a lot of people eat on the way to office or get some snacks for their day at the office. One interesting response states that the participant doesn't plan anything when going out for a walk without a particular goal.

5.3   Analysis of machine generated routes

In this section, the detailed analysis of machine generated routes has been presented. As mentioned in section 3.4, Google Maps and GraphHopper were used as routing engines for the purpose of this study, this section will discuss about the routes generated using these routines engines in all the three given scenarios.

For the scenario of *Travelling to work place,* the route generated by Google Maps were the optimum by considering best travel time and route length. Since in our case the length of the route is not very much, it is hard to compare the routes by length because

all three of them just differ by each other by about 40-50 meters. The other metric indicators such as sidewalk and smoothness were the best in the route generated by Google Maps. As per our research findings, Google Maps didn't really consider the green area and amenities much when deciding a route. So, we can conclude that Google takes into account the time and speed more over other factors. On the other hand, route generated by GraphHopper using the OSM database has a shorter distance compared to google but it still shows the same travel time as google. In our study, GraphHopper generated route considered more green area since it also considered secondary roads with average surface smoothness, which could also be the reason for having same travel time as Google Maps. But we can conclude that results suggested by Google Maps were more optimum for the given scenario considering all weather routing. Some studies suggest that to calculate the travel time Google uses historical speeds, average speed of peer users, road/traffic detector data if available as well as elevation (What Speed Does Google Maps Use for Walking - CMC Distribution English, 2022). Since the different mobile devices used for navigation have different positioning accuracy, you can sometime get a slight difference in actual time and predicted time.

For the second scenario, *Leisure walk,* the route suggested by GraphHopper was the shortest but not fastest. In this scenario, there was a shift in green area metrics as compared to previous one as the route suggested by Google Maps were having more green area coverage than route suggested by GraphHopper. In both the scenarios, *Travelling to work place* and *Leisure walk* the route suggested by google had the best surface smoothness. Regarding our metric indicator 'Illumination', none of the routing engines considered this in their route suggestion. Since Google also takes real-time traffic into account, it adjusts the travel time by also taking into account traffic signals. But the question here is, do we really need traffic data while planning a leisure walk? since most of our participants mentioned that they would like to walk in a green and quite zone which basically means away from main traffic streets. By analysing the routes suggestion in both the scenarios, we can say that Google Maps considers travel time over route length while GraphHopper considers route length over travel time.

For the third scenario, *Bike trip on a weekend*, both Google Maps as well as GraphHopper suggested the routes without dedicated bike lane and least green area coverage. These routing engines also suggested the shortest and fastest routes compared to manually generated route, but none of the routing engines complied with the user demand that we received in the first user survey; which were dedicated bike lane due to safety reason, green area and low noise level. Considering the metric indicator 'Noise level' and safety, both the routing engines suggested to take the main state highway which has a speed limit of 80km/h and a high density of traffic. This result shows that these two routing engines always give priority to travel time and distances over all other metric indicators in a bike route scenario. Also the routes suggested by both the routing engine in this scenario were almost same.

In all the three scenarios that were considered for the purpose of this study, the two routing engines didn't take most of the human preferences into account when suggesting or generating a route. So, we can conclude that these routing engines are good if you want to arrive somewhere with a time bound deadline. But if you do not have a time limits, using these routing engines might not be a good and healthy choice.

6 CONCLUSION AND OUTLOOK

In this section, the main findings of this research will be summarized. Though the results and findings have been discussed in section 5, in subsection 6.1, the summary will be discussed by answering the research questions formulated and proposed in section 1.2.2. Finally, the thesis will finish by discussing the possible directions for future work in subsection 6.2 below.

6.1 Summary

Research question 1: *Are the planned routes provided by dominant apps optimal? How are the optimum criteria defined here?*

For the scenario *Travelling to work place*, the route generated by Google Maps was optimum in the sense that it matched the survey participants' demand for the shortest and fastest route. As we also mentioned in section 5.3, Google Maps considers travel time and distance as the most important above all other metric indicators in its route generation. Also, the route suggested by Google Maps appeared to be the most optimum all-weather route. For the purpose of this study, we have considered using participants' priority of metric indicators as the optimum criteria. On the other hand, GraphHopper considered more green areas and inner streets while generating the route in the given scenario but the travel time was not lesser than Google Maps. While in the *Leisure walk* scenario, the route generated by Google Maps was longer than the route generated by GraphHopper. But Google Maps showed the least travel time, hence we can conclude that Google Maps consider the fastest route over the shortest route. On the other hand, GraphHopper considers the shortest route over the fastest route.

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But in every scenario, Google suggested a route was optimum for all-weather routing. We can also conclude that none of the routing engines showed convincing results for the participants' demand for the *Leisure walk* and *Bike trip on a weekend* scenario. As mentioned earlier, user preferences are considered as a measure of optimum criteria, we can say that the routes suggested by these routing apps were not optimal in all three scenarios.

Research question 2: *Why do different apps provide different results? Considering our set of metric indicators, how similar are the routes from two different apps?*

Different routing apps use different algorithms backend. Google Maps has its custom build algorithm which seems to consider travel time as the most important element. While the GraphHopper has Dijkstra algorithm running backend which considers distance as the most important element in route generation. The results were not very different in terms of all other metric indicators except travel time and length. If we compare the similarity of the routes generated by the routing apps in all three scenarios, the route generated by both the apps in the *Bike trip* scenario was very similar. But for the *Leisure walk* and *Travelling to work place*, the routes were only about 50-60% similar to each other. One important thing to note here is that, for walking scenarios, the length of the route is not very large which might introduce a limitation in the performance of these apps. Another important factor could be a greater number of traffic lights along the route to see how the performance of the apps differs.

Research question 3: *How will a human plan the same routes under the same conditions? How different will it be from the machine-generated routes?*

The first user survey was conducted to know the human preferences for a route under different circumstances or scenarios. The findings from the first user survey indicated how people's route choice preferences vary with the scenario. As mentioned in section

5.1 and 5.2, while walking to work place, people generally consider the shortest and fastest route while other factors such as amenities, noise level, green area, etc. are not that important. But for the scenario *Travelling to work place*, where the first user survey indicated that the type of surface was not an important element, the second user survey contradicted it as most of the participants considered the type of surface an important deciding factor for all weather routing. Considering our user surveys, Google Maps route suggestion was closest match in line with human preferences of a route while walking to work place and this hypothesis was confirmed during the second user survey when most of the participants choose the route generated by Google Maps as their preferred choice.

On the other hand, the human route choice preferences for the scenario *Leisure walk* were completely different from the previous scenario, where the length of the route and travel time were one of the least important elements in choosing a route. In this scenario, the participants voted green area, sidewalk availability and low noise level as the most important deciding factors. These results from the first user survey were validated when most of the participants choose the manually generated route over the machine-generated route as none of the machine-generated routes considered the human preferences for this scenario. In the Leisure walk scenario, the manually generated route was the best match to human preferences as per the first user survey. Hence, we can say that the route suggested by routing engines and the route preferred by humans were completely different.

In the third scenario, *Bike trip on a weekend*, the route generated by routing engines was not at all in line with human preferences. If we would consider the participants' main concern in this scenario, they would like to bike on low or no-traffic roads since it gives them a sense of safety. But the routes suggested by routing engines guided us through the very busy and high-speed roads. Even though the routing engines showed the fastest and shortest route, for participants, it was not an important factor. Hence, we can conclude that human route choice behavior changes abruptly with the scenarios while routing engines have a static mechanism for calculating routes. They just show you the walking route but they are the same for all the walking scenarios.

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Research question 4: *Which route should we follow in a given scenario?*

As per our research, there is no clear answer to this question which suits all three scenarios. The answer to this question depends heavily on the purpose of travel. As discussed before, if you want to travel to the office, Google Maps might be the optimum choice considering its all-weather route characteristics and the least travel time. While if you want to go out for a leisure walk, following routing engines might not be the best idea as you can miss the things which are important for you along the route. Also, it depends on the individual's choice of point of interest or the metric indicators, but generally speaking, you can miss the clean air, quiet and peaceful zones and a couple of amenities. Also slope or difficulty level could be a deciding factor for some people but they were hardly playing any role in our research route.

For the bike trip scenario, it is very clear from this research that using these routing engines will not give you the route you want. So, in case of bike trip, it can be a good idea to ask some local guide or try some other routing engines which might be better suited for biking.

6.2 Limitations and future research

Due to the time constraints, an important area of investigation that was left out is driving routes. It would be really interesting to see what kind of results we get if we do the same experiments with different routing engines used for driving routes.

Also, in terms of this research, it could be very informative to extend this research to more complicated routes with more distance and travel time. Significantly larger walking routes could be useful to verify the findings of this research and to generalize it over a large area or dataset. When a route has more length and more turns, the routing engines can perform very differently. Another important test consideration could be the difficulty level depending on the slope of the routes chosen.

Another direction where this research can also be extended would be considering various other scenarios and seeing the participants' responses to the metric indicator preferences. As mentioned, with a large shift in preferences due to changes in scenarios, it is highly likely that we can get interesting findings which can help us understand the human route choice behavior better.

An important and big step could be the development of a routing algorithm based on the findings of this study and the same approach tried with some more participants to get a more generalized result. As of now, the most popular routing engines just give you choice to select between different modes of travel such as walking, biking, public transport and driving. The routing algorithm based on this research can provide users with more scenarios to choose from in the same mode of travel such as walking and biking.

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Appendix

The appendix includes screenshots of the web-based questionnaire used in the first and second user studies. It is accordingly divided into two parts: A - First user study, and B - Second user study.

A

First user study

Routing preferences under different scenarios - User study 1

This user study is a part of M.Sc. Cartography Master's thesis and aims to investigate the users' priority for their route preferences in three different scenarios.

· · ·

* Required

Participant's details

1. **Which age group do you belong to** *

   ○ below 20

   ○ 20-34

   ○ 35-49

   ○ 50 and above

2. **Your gender** *

   ○ Woman

   ○ Man

   ○ Other

   ○ Prefer not to say

3. **How frequently do you commute:** *

	Every day	Couple of times a week	Couple of times in a month	Very rarely	Never
on foot	○	○	○	○	○
by bike	○	○	○	○	○
public transport	○	○	○	○	○
driving	○	○	○	○	○

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Traveling to work place

Scenario 1: Imagine that you walk to your office from your home every day

4. While walking to my office I take into account the following: *

Please order the answers by dragging them up and down as per your preferences; the item with the highest priority should be on the top:

1	Type of surface / wheelchair accesibility
2	Total length of the route
3	Number of turns / crossings
4	Slope
5	Air quality index / green area
6	Noise level
7	Amenities (benches, waste bins, public toilets, drinking water, shade, etc.)
8	Estimated time of arrival
9	Number of underpasses (underground crossings)
10	Sidewalk availability

5. Anything else that you take into account in Scenario 1 but is not in the list:

optional

Enter your answer

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Leisure walk

Scenario 2: Imagine a situation when you want to go for a walk during your free time

6. **While going for a leisure walk I take into account the following:** *

Please order the answers by dragging them up and down as per your preferences; the item with the highest priority should be on the top:

Noise level
Estimated time of arrival
Number of turns / crossings
Air quality index / green area
Slope
Amenities (benches, waste bins, public toilets, drinking water, shade, etc.)
Type of surface / wheelchair accesibility
Illumination
Sidewalk availability
Total length of the route ↑ ↓

7. **Anything else that you take into account in Scenario 2 but is not in the list:**

optional

Enter your answer

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Bike trip on a weekend

Section 3: Imagine a scenario where you are going for a bike trip on a day off or on a weekend

8. **While planning a bike trip I take into account the following:** *

Please order the answers by dragging them up and down as per your preferences; the item with the highest priority should be on the top:

Number of turns / crossings
Air quality index / green area
Estimated time of arrival
Type of surface
Dedicated bike lanes
Noise level
Total length of the route
Slope
Illumination
Amenities (benches, waste bins, public toilets, drinking water, shade, etc.)

9. **Anything else that you take into account in Scenario 3 but is not in the list:**

optional

Enter your answer

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B

Second user study

Routing preferences under different scenarios - User study 2

This user study is a part of M.Sc. Cartography Master's thesis and aims to investigate the users' priority for their route preferences in three different scenarios.

...

* Required

Participant's details

1

Which age group do you belong to *

○ below 20

○ 20-34

○ 35-49

○ 50 and above

2

Your gender *

○ Woman

○ Man

○ Other

○ Prefer not to say

3

Please write three most important things that you would take into account when planning a walking or biking route? *

(You can also write just three keywords)

Enter your answer

Next

Traveling to work place

Scenario 1: Imagine that you walk to your office from your home every day

4

The following three route options have the same source-destination pair. Based on the given description, please select one route that you would like to consider while walking to the office everyday: *

(**ETA** = Estimated Time of Arrival)
(**Smoothness** refers to the surface smoothness; **Poor** smoothness refers to the unpaved path)

A

1	Length	1.4 Km
2	ETA	17 min
3	Sidewalk	Yes
4	Smoothness	Good
5	Crossings	2
6	Green area	30 %
7	Trash bin	2
8	Bench	3

B

1	Length	1.36 Km
2	ETA	17 min
3	Sidewalk	Partly
4	Smoothness	Average
5	Crossings	2
6	Green area	55 %
7	Trash bin	2
8	Bench	3

C

1	Length	1.33 Km
2	ETA	15 min
3	Sidewalk	No
4	Smoothness	Poor
5	Crossings	1
6	Green area	80 %
7	Trash bin	3
8	Bench	4

Map legend: −− Track   Starting point   Trash bin   Bench   Green area   Destination

◯ Route A

◯ Route B

◯ Route C

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Additional comments, if any?

optional

Enter your answer

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Leisure walk

Scenario 2: Imagine a situation when you want to go for a walk during your free time
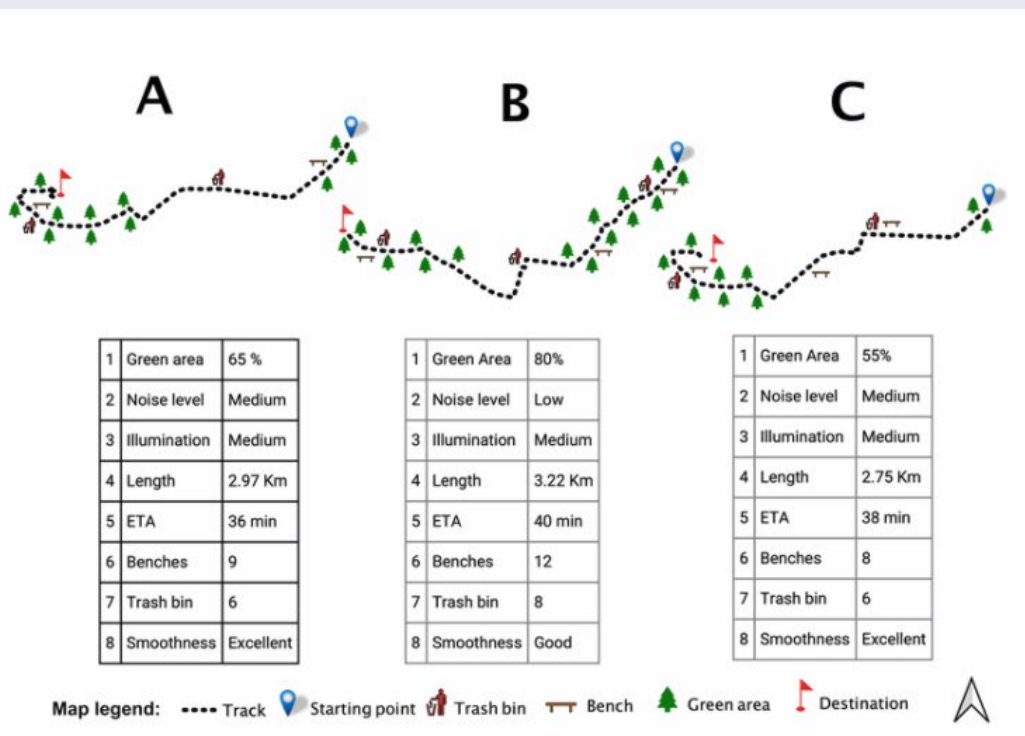
6

The following three route options have the same source-destination pair. Based on the given description, please select one route that you would like to consider while going for a leisure walk: *

(**ETA** = Estimated Time of Arrival)
(**Smoothness** refers to the surface smoothness)

	A	
1	Green area	65 %
2	Noise level	Medium
3	Illumination	Medium
4	Length	2.97 Km
5	ETA	36 min
6	Benches	9
7	Trash bin	6
8	Smoothness	Excellent

	B	
1	Green Area	80%
2	Noise level	Low
3	Illumination	Medium
4	Length	3.22 Km
5	ETA	40 min
6	Benches	12
7	Trash bin	8
8	Smoothness	Good

	C	
1	Green Area	55%
2	Noise level	Medium
3	Illumination	Medium
4	Length	2.75 Km
5	ETA	38 min
6	Benches	8
7	Trash bin	6
8	Smoothness	Excellent

Map legend: ···· Track 📍 Starting point 🗑 Trash bin ⊤⊤ Bench 🌲 Green area 🚩 Destination

○ Route A

○ Route B

○ Route C

7

Additional comments, if any?

optional

Enter your answer

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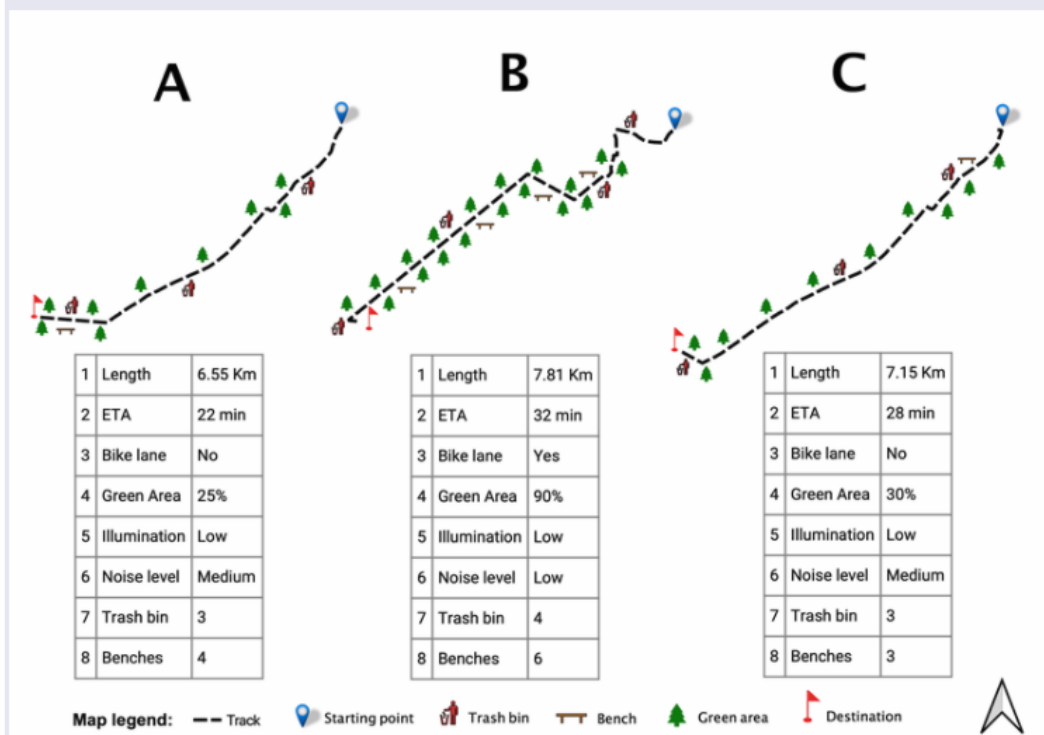
71

Bike trip on a weekend

Section 3: Imagine a scenario where you are going for a bike trip on a day off or on a weekend

---

8

The following three route options have the same source-destination pair. Based on the given description, please select one route that you would like to consider while going for a bike ride: *

(**ETA** = Estimated Time of Arrival)
(**Smoothness** refers to the surface smoothness)

A			B			C		
1	Length	6.55 Km	1	Length	7.81 Km	1	Length	7.15 Km
2	ETA	22 min	2	ETA	32 min	2	ETA	28 min
3	Bike lane	No	3	Bike lane	Yes	3	Bike lane	No
4	Green Area	25%	4	Green Area	90%	4	Green Area	30%
5	Illumination	Low	5	Illumination	Low	5	Illumination	Low
6	Noise level	Medium	6	Noise level	Low	6	Noise level	Medium
7	Trash bin	3	7	Trash bin	4	7	Trash bin	3
8	Benches	4	8	Benches	6	8	Benches	3

Map legend: – – Track   Starting point   Trash bin   Bench   Green area   Destination

○ Route A

○ Route B

○ Route C

9

Additional comments, if any?

optional

Enter your answer

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