Geographical Information Management and Applications

Cyclists route choice: analysing the greenness of the built and rural environment

Thesis report

Harmke Vliek
6854818

26th February 2021

Cyclists' route choice: analysing the greenness of the built and rural environment

Harmke Vliek
6854818
harmkevliek@hotmail.com

Supervisor Dr. C. (Kees) Maat
Faculty of Civil Engineering and Geosciences
TU Delft

Professor Prof. dr. Ir. P.J.M. (Peter) van Oosterom
Faculty of Architecture and the Built Environment
TU Delft

26th February 2021

Acknowledgements

Cycling is such an intrinsic part of my life that I have never actually thought about it as a conscious choice. For me, cycling is the most important way to go from A to B, whether it is a commute, cycling for leisure or even cycling holidays. Even though this thesis was written during a nationwide lockdown, cycling was still possible. This was a great way for me to convert this time into a way to contemplate research designs and interpretation of results. The subject of route choice behaviour inspired me and the people who surround me to think about why we prefer to cycle a certain route over another, and the factors that influence route decision, resulting in interesting discussions. So, as part of the master Geographical Information Management and Applications, I present to you my final thesis titled: *Cyclists' route choice: analysing the green built environment.*

Completing this research would not have been possible without the help from many people to whom I would like to express my gratitude.

First of all, I would like to thank my supervisor, Kees Maat from the TU Delft, for his continued support and feedback. When I was stuck on certain matters of my research, Kees offered new insights which allowed me to continue my research on alternative paths. On that note, special thanks goes out to Jimme Smit and Maaike Kuiper for performing the data collection and spatial indicator preparation together and debating different problem solutions; our morning meetings were a great start of each day.

Secondly, this thesis would have not been possible without the required data. Thus, I would like to thank the Fietsersbond for supplying their network file and corresponding spatial information. In addition, special thanks goes out to all volunteers who cycled with the GPS trackers and completed our survey, both in the preliminary research and the main study. Moreover, I would also like to thank Danique Ton from the TU Delft, for providing new insights into alternative path generation and Dirk Bussche from the Hogeschool Breda for his consultation on fixing the topology of the Fietsersbond network. You both warned me that the project was very ambitious and that I should not expect to create a fully developed model, so your input was valuable both for the research process and achieving a realistic model.

Finally, I would like to thank my friends and family for keeping me sane during a thesis written in a lockdown, their continuing support, their willingness to be tracked with GPS trackers and attendance at the motivational morning meetings, and all the proofreading I asked from them.

Amsterdam, 26 February 2021

Abstract
The Dutch government aims to promote bicycling because it causes less pollution than motorized forms of transport and it has a positive effect on the health of the bicyclist. To promote cycling, the cycling infrastructure and its surrounding environment requires attractive qualities so that people perceive cycling as the most attractive option. It is well established that the built environment influences cyclists' route choice behaviour. This study aims to determine the influence of the green environment on cyclists' route choice behaviour, both in rural and urban context. In this setting, the green environment is defined as "the components of greenery, water, bridges and aesthetic that make up the built environment".

The hypothesis is that that people choose to cycle along natural components such as greenery and proximity to water, even if they have to detour from the shortest route. To test this hypothesis, volunteers were tracked with a GPS for the duration of seven days, after which they filled in a survey requesting their personal information and cycling preferences. Based upon observed paths of GPS-tracked participants, a choice set of labelled paths between origin and destination is generated. Subsequently, a conditional logit choice model is estimated in the statistical software program Stata, in order to find statistically significant effects of green environment characteristics and personal characteristics on route choice behaviour.

The result of this study is that the influencing features of the green environment are a combination of water, greenery, and the environments' aesthetic; with the finding that the influence of the green environment is different in urban areas than in rural areas. In an urban context, people choose to cycle through greenery, close to water and through appealing environments whereas in a rural environment, just water and the environments' aesthetic influence route choice positively.

Table of contents

List of Tables and Figures

Tables

Figures

1

Introduction

1.1 Problem and its Context

Some say that in the Netherlands, everybody cycles (Feddes, de Lange & Brömmelstroet, 2020; p. 133). Dutch infrastructure is very welcoming to bicyclists, thereby encouraging them to cycle (Hull & O'Halloran, 2014). In fact, the Dutch cities Utrecht and Amsterdam have headed the Most Bicycle Friendly Cities list until 2013, when Copenhagen passed both cities due to a lack of innovation (Copenhagen IZE index, 2019). This slight reduce of bicycle friendliness and thus the amount of people choosing to cycle is reflected in Dutch policy, which aims to promote the bicycle with the plan Tour de Force (Fietsberaad, 2020). A part of the Dutch population is able to cycle more than they actually do, for example choosing public transport instead of the bicycle for a short distance. Tour de Force aspires to encourage 200.000 commuters to ride their bicycle to work for either a part of the trip or the whole commute trough innovation.

The Dutch government aims to promote cycling due to various reasons. The benefits of cycling more are clear and extensively researched; taking the bike to work rather than the car or public transport causes less pollution as well as providing a positive effect on the health of the commuter (Johansson et al., 2017). Additionally, cycling relieves pressure on the public transport system (Sun & Zacharias, 2017) and provides a solution for various spatial challenges such as parking problems, traffic flow and safety (Feddes et al., 2020; p. 140). For the government to promote cycling, the cycling infrastructure and its surrounding environment requires attractive qualities so that people actually prefer to cycle for at least part of their journey.

Regardless of the attractiveness of the cycling infrastructure, its surroundings are assumed to be important as well. According to Ewing and Cervero (2010), features of the built environment influence activity in their environment. The built environment is "the human-made space in which people live, work, and recreate on a day-to-day basis" (Roof & Oleru, 2008; p.24). It consists of buildings, parks or green spaces to neighbourhoods and cities, including their supporting infrastructure such as road networks and water supply (Ngosong, 2015). The waterfront is an example of a component of the built environment. An attractive built environment attracts more activity (Specht, 2014). In this research, the built environment is defined as a material and spatial entity. Various authors, including Cervero, Sarmiento, Jacoby, Gomez & Neiman (2009) find that even though road facility design, street density, connectivity, and proximity to cycle paths, are associated with an increase in cycling because of an increase in safety and easier access, other attributes of the built environment such as density and land-use mixtures, are not.

Moudon et al. (2005) state that the decision to start cycling is only moderately associated with the built environment. According to them, both the decision to cycle and cycling as means of transport largely takes place irrespective of environmental prompts or barriers, and independently from traffic conditions. However, Wang, Chau, Ng, & Leung (2016) state that mixed land use and factors of landscape design such as greenery, presence of public space and the availability of separate cycling tracks have a positive effect on bicycle use since people prefer to encounter these factors of landscape design in a way where they can enjoy them. If green indeed proves to have a positive effect, then municipalities can stimulate cycling further by providing greener routes.

The evidence pool on the influence of the built environment on route choice of bicyclists is not very dense. Nevertheless, bicyclists in the Netherlands have many possible routes to consider whenever they are traveling somewhere, due to the extensive cycling infrastructure in the Netherlands (Ton, Cats, Duives & Hoogendoorn 2017). Especially in cities, people encounter many intersections and other options to alter their route. The chosen routes indicate route preference because the characteristics between routes vary in their attractiveness, such as the shortest route versus a detour along the waterfront. Route preference has been researched based on multiple indicators. Studies that were executed outside the Netherlands indicate that the percentage of separate cycling lanes is an important factor for route choice (Hood, Sall & Charlton, 2011; Casello & Usyukov, 2014). Conversely, in the Dutch context Ton et al. (2017) found no significant relation due to the layout of Dutch infrastructure, which is protective regarding cyclists. Other factors that influence route choice negatively are the number of intersections per kilometre, the number of stop signs per kilometre and the number of turns per kilometre (Hood et al., 2011; Broach, Dill & Gliebe, 2012). According to Broach et al. (2012) and Ton et al. (2017), the factor distance is valued differently throughout the day; the effect is more negative during peak hours than during the rest of the day.

There is a slight indication that green in the built environment influences cyclists' route choice. Menghini, Carrasco, Schüssler, & Axhausen (2010) found that bicyclists state that they prefer to cycle close to green areas. However, this preference is not visible in the route they take. Moreover, Vedel, Jacobsen, & Skov-Petersen (2017) state that commuters are willing to cycle longer distances if their route passes a green environment. These findings indicate that current research into the influence of greenery in the built environment has been performed on a surface level, offering the potential to examine this influence more extensively.

In this thesis, it is hypothesised that people choose to cycle along natural components such as greenery and proximity to water, even if they have to detour from the shortest route. It aims to describe the influence of greenery in the built environment on route choice of bicyclists. The thesis contributes to earlier cyclist route preference research by introducing a new approach to route choice identification based on indicators in the green built environment. These indicators will be identified based on a literature review as well as a qualitative preliminary study. Previous research regarding travel and the built environment has primarily focused on route choice behaviour in different transit modes. Furthermore, research on the influence of the built environment regarding route choice is less common, especially research that focusses on the green built environment (Ewing & Cervero, 2010; Cao, Mokhtarian, & Handy, 2009; Mokhtarian & Cao, 2008). Current research is more focused on bike sharing systems and the influence of the built environment, whereas this study is focused on personal bikes (Aziz et al., 2018; Lin et al., 2018). Moreover, rather than just modelling tracked GPS coordinates similar to Ton et al. (2017), every participant completes an additional survey for each tracked route. The survey provides additional insight into individual characteristics and motivations for route choice, thereby providing possible new insights for both policy makers and scientists.

1.2 Research goal

The goal of this study is to determine the influence of the green built environment on bicyclists' route choice in order to contribute to better routes. The green built environment encompasses the components of the built environment that are characterised by natural influences. The positive mental effect of encountering greenery has been researched extensively (Depledge, Stone & Bird, 2011). Green elements of nature provide positive short-term effects on both self-esteem and mood. Water has an even more positive effect. It is expected that people actively seek out natural components in order to reset their mind on their way to work or to make the cycling trip a pleasant experience.

As the previous section indicated, indicators of the built environment that influence route choice have been analysed on a broad scale. This study will focus on the influence of the green built environment, thus providing a more in-depth analysis. For this purpose, more insight in the role of the green built environment is required. The following research question will make determining this role possible:

“How and to what extent does the green built environment influence bicyclists’ route choice in the Netherlands?”

For the main research question to be answered, sub questions have been composed. These sub questions are divided into two categories; a preliminary research in which the indicators of the green built environment are determined, and the analysis that answers the research question. The green built environment is a broad term; therefore the preliminary research question is required in order to provide a demarcation of the term green built environment that is relevant for this research.

Preliminary research sub question

- What are spatial indicators of the green built environment according to bicyclists in Zwolle?

Research sub questions

- To what extent do people diverge from the shortest route?
- To what extent is there a difference between indicated and observed preference for the green environment of cyclists?
- How do green environment characteristics influence route choice of bicyclists?
- How do personal characteristics influence route choice of bicyclists?

The terms in the research sub questions are henceforth explained. The shortest route concerns the route that requires the least amount of cost to be cycled. In the context of cycling, cost is usually the distance or travel-time since cycling is essentially free. Indicated preferences are preferences that people say they have, which are revealed in the survey. The observed preference regards the revealed preference from cyclists which is revealed by the GPS trackers. Personal characteristics of cyclists are variables such as age and sex. They are used to describe interaction effects.

1.3 Research scope

Since the subject of this thesis is route choice behaviour of cyclists, cycling behaviour must be defined. Cycling behaviour is defined as “The choice people make for a bicycle route”. It is thus an overarching term that encompasses all choices the participants make during their trips. The choices made by the cyclists are evident when they are tracked; each junction of the road provides an opportunity to extract the choice they made regarding their route. Moreover, this research focuses on the green built environment. This means that other aspects of the built environment such as traffic lights are not considered. Additionally, all cycling trips of the participants are considered, regardless of the purpose of the trip. Furthermore, the research scope is limited to the Netherlands, since all data collection will be performed in the Netherlands.

1.4 Research methodology

The research methodology can be divided into five stages: preparation, data collection, data preparation, indicator preparation and the statistical analysis. The preparation phase consists of an overview of related research combined with a preliminary study to determine indicators of the green built environment. The stage of data collection involves Volunteer Geographical Information; following volunteers with GPS trackers and requesting them to complete a survey providing insight in their personal characteristics. The step data preparation consists of the separation of the retrieved GPS points by speed to determine which points comprise a cycling trip. These cycling trips points are then map matched to the Fietsersbond network dataset, thereby creating the observed routes and origin and destination (OD) pairs for each route. These OD-pairs are then used to generate labelled route alternatives. The subsequent phase is the indicator preparation phase, in which the spatial indicators are valued based on the information in the Fietsersbond network and from other data sources, after which they are assigned to all routes. Finally, the last step statistical analysis is executed with the software

Stata, in which models are estimated to determine the influence of spatial indicators of the green built environment and personal characteristics on route choice behaviour.

1.5 Report outline

This report consists of seven Chapters. Chapter 2 discusses related research regarding the relationship between cycling, the built environment, and individual characteristics. Thereafter, Chapter 3 provides the qualitative preliminary study that laid the foundation for this research. The choices regarding the application of existing methodology are motivated in Chapter 4. Chapter 5 describes the results of this study's analysis. These results are then interpreted in Chapter 6; the discussion, thereby discussing research limitations. This report culminates in a conclusion in Chapter 7, in which the research questions are answered.

2

Literature

The theoretical background provides insight into what spatial indicators of the green built environment are according to literature. It consists of first section 2.1 which describes the context of route preference choice models. Thereafter indicators of the built environment in previous research are discussed in section 2.2. Subsequently, indicators of personal characteristics are described in section 2.3.

2.1 Route preference

The built environment is a determining factor in choosing a cycling route, even more than perceived travel time (Olde Kalter & Groenendijk, 2018). Studies researching the influence of the built environment are generally divided into two categories; stated preference and revealed preference.

2.1.1 Stated preference

Stated preference methods reveal the preference of respondents based on surveys. This means choice preferences are not based on real-world situations but chosen in controlled environments staged by researchers (Yang & Mesbah, 2013). These situations provide choices based on trade-offs, a longer route with enjoyable scenery versus a shorter route with traffic lights for example. Stated preference methods are an attractive option in cycling research because the choice environment is easily controllable and cheap. Other advantages are the method being flexible and able to deal with many variables, it is relatively easy to create a large sample size (Kroes & Sheldon, 1988; Yang & Mesbah, 2013; Broach et al., 2012). On the other hand, stated preference methods contain the significant disadvantage that, for the method to be reliable; people have to act exactly as they state they do (Kroes & Sheldon, 1988). Moreover, respondents are required to visualize given choices while lacking a real-world context. This is very difficult (Broach et al., 2012). Furthermore, because of the widespread capability of the method, the number of variables used to characterize route choices are probably restricted due to the survey having to be applicable to all respondents (Yang & Mesbah, 2013). If respondents live in different living environments, just the shared variables can be compared.

2.1.2 Revealed preference

Contrary to stated preference, revealed preference tracks the actual movements of participants, either by keeping a travel diary or more recently, with GPS trackers. Before the use of GPS trackers, cyclists were most commonly asked to recall routes. These routes were then compared to optimal path routes, providing the advantage of using actual routes and network data. Drawbacks, however, are the ability of cyclists to accurately detail their route and the limited choice sets (Altman-Hall, 1996; Broach et al., 2012). Since 2007, revealed preference studies with GPS tracking devices have become more popular (Pritchard, 2018). The advantage of GPS devices is that there is no option for participants to confuse their routes contrary to the use of travel diaries. Other advantages are the accuracy of positioning and the constant stream of data from the participants. Disadvantages are data loss due to technical errors or batteries that are not charged. Moreover, bias of participants influences revealed preference less than with stated preference, since cycling a different route requires more effort than picking a different image (Yang & Mesbah, 2013). Collecting data at individual level every few seconds results in very large datasets. Large datasets based on GPS points for creating route choice models come with difficulties; increasing computation time, sample bias and noise during data collection (Mengheni et al., 2010; Hood et al., 2011; Ton et al., 2017). Due to the large file size of GPS data, either small samples were commonly used, or personal characteristics were not taken into account.

People choose to cycle their route for a reason. Route choice modelling offers a wide variety of options to determine motivating factors for route choice. Travel behaviour studies primarily apply the random utility theory. The random utility theory assumes that routes are chosen in order to try to maximize utility; thus finding the optimal combination of factors according to the travellers' preferences (McFadden, 1977; Dane, Feng, Luub & Arentze, 2019). For example, if people prefer to cycle along the waterfront rather than high-rise buildings but their way would be shorter along the buildings; then the utility of the factor waterfront determines whether the cyclist will cycle a longer distance to ride past it.

The revealed preference study of Hull & O'Halleran (2014) found that important factors that influence the choice for cycling are safety, comfort, continuity, and speed. Stated preference routes reveal that safety and comfort are reasons for choosing cycling routes over other cycling routes (Stinson & Bhat, 2002; Sener, Eluru & Bhat, 2009). An example of safety is the presence of street lighting. Likewise, an example of comfort is the lack of traffic noise or traffic lights. This study is a revealed preference study with an extra survey for indicated preferences. It thereby assumes that route choices are based on the utility of features of the built environment as described in section 2.2 and cyclists' personal characteristics, discussed in section 2.3.

2.2 Features of the built environment

It is to be expected that people choose the shortest route since it minimizes time and effort. The absolute shortest route; cycling as the crow flies, is often not possible due to the road network that forces a cyclist to divert from the straight line. The denser the road network is, the more a straight line can be approached. Therefore, urban areas offer a closer approach to the absolute shortest route than rural areas because the road network is simply denser. However, cyclists generally do not choose the shortest route possible (Dill & Gliebe, 2008; p. 2). People choose to cycle along stores to combine trips or choose to divert from the shortest route due to the wish to cycle in for example green areas or along water. It has been proven that the built environment influences route preference (Cervero & Kockelmann, 1997; Olde Kalter & Groenendijk, 2018). Green areas and water in urban environments in the context of the shortest route are ambivalent; on one hand they provide short cuts and a reprieve from the business of the city whereas they also raise barriers since the road network is planned around water and greenery. Greenery and water are experienced differently as well. In good weather, they can provide a place to clear your mind and experience nature. When it is cold or dark however, green areas and water can be daunting due to a lack of lightning, less people being around and a lack of other indicators that contribute to personal safety (Depledge et al., 2011; Skov-Peterson et al., 2018).

Research has shown that green and water influence route choice. This research has primarily taken place in an urban context. Green and water are part of and thus variables of the built environment. These variables can be divided into two categories; macro- and microscale factors (Swinburn, Egger & Raza, 1999; Mertens et al., 2016). Macroscale variables are urban features such as the cycling road network and land use. Microscale variables regard the relatively small factors such as a traffic light, vegetation, or speed bumps (Mertens et al., 2016). Research that has been conducted on macro scale factors is consistent in its findings; a higher urban density and an extensive cycling network lead to more cycling (Van Dyck et al., 2012; Menghini et al., 2010). Conversely, a consensus on micro scale environmental variables has not been reached (Mertens et al., 2016). Research that illuminates the influence of the green built environment on route preference has an almost macroscopic approach; primarily focusing on greenery, aesthetics, and water. Opposite factors of the green environment are noise, busy roads, and traffic lights.

2.2.1 Greenery and water

Greenery and water are the main features of the green built environment. Greenery encompasses the greenness of the environment, ranging from industrial areas who are decidedly not green to forests and nature, which are regarded the height of green environment. Water encompasses all water in the built environment, ranging from small ponds and streams to canals and lakes. Commuters are willing to cycle longer distances if their route passes a green environment, whereas a busy road and interruptions cause people to choose another route (Vedel et al., 2017). Cole-Hunter et al. (2015) and Mertens et al. (2017) agree that there is a positive association between cycling and the presence of greenery. Olde Kalter & Groenedijk (2018) confirm that in the Netherlands, a green environment influences cycling positively. People are willing to cycle further in order to pass green areas and water bodies as this environment can prevent noise and wind and lowers temperature (Chen et al., 2018; Ghanayim and Bekhor, 2018; Sarjala, 2019). Krenn, Oja & Titze (2014) found that actual cycling routes in Australia pass more green and aquatic areas than the shortest routes. Hochmair (2005) identified parks as an important criterion for route choice.

By way of contrast, Nello-Diakin & Harms (2019) state that this positive association does not seem to be applicable in a mature cycling context such as in the Netherlands. Amsterdam is able to provide a suitable environment for cyclists throughout the entire city, therefore not principally restricting cyclists to green areas. Similar findings are brought forward by Dessing et al. (2016), who find that observed cycling routes of children in Amsterdam contain less trees than the shortest route they can cycle. Furthermore, Skov-Peterson et al. (2018) state that green areas are sometimes avoided by cyclists due to the fact that there is less street lighting and therefore feels unsafe.

2.2.2 Aesthetics

The aesthetic of the route and liveliness on the road influence the amount of cycling along that route positively (Gehl, 2010; Van Dyck et al., 2012). Other studies confirm positive associations between an aesthetic environment and cycling for transport (Lee and Moudon, 2008, Wendel-Vos et al., 2004). Hochmair (2005) identified sights as an important criterion for route choice. Olde Kalter & Groenedijk (2018) identified variables of the built environment that influence cycling positively and negatively in the Netherlands. This research is focused on the choice of mode of transport to work. According to their study pavement cafes influence the choice for cycling positively.

Alternatively, Kondo et al. (2009) found no significant relation between aesthetic and the attractiveness of a cycling route. Van Holle et al., (2012) corroborate this and have not found an association between aesthetics and cycling for transport because cycling for transport is about finding the fastest route. Moreover, Bernardi et al. (2018) confirmed that routes in the Netherlands are not related to beauty as the majority of the study sample contains routes with a high level of aesthetic and participants found it hard to detect a difference.

2.2.3 Noise

The impact of noise on bicyclists is widely recognized but seldom quantified. Since bicyclists often share a road with or adjacent to other traffic, bicyclists are exposed to high levels of traffic noise, resulting in high stress levels that cause stress reactions such as tinnitus, sleep disturbance and anxiety (Poenaru et al., 1987; Ouis, 2001). Noise is thus both a potential health risk for cyclists as well as an annoyance (Gössling, Humpe, Litman & Metzler (2019). Gössling et al. (2019) found that German-Austrian bicycle organization members cycle 6.4% longer distances; on average 7.2 km per week, to avoid traffic impacts such as noise. Winters, Teschke, Grant, Setton & Brauer (2010) found that the most influential criteria on travelling by bicycle are related to noise and air pollution; 96% of the respondents indicated that they would be more likely to cycle along a route away from traffic noise and air pollution.

2.2.4 Busy roads and traffic lights

Busy roads and traffic lights influence cyclists route preference (Dessing et al., 2016; Menghini et al., 2010; Bernardi et al., 2018). There is no consensus whether traffic lights are avoided or favoured by cyclists. Broach et al. (2012) and Krenn et al. (2014) found that cyclists avoid traffic lights due the delaying influence traffic lights have on a route. Adversely, Dessing et al. (2016) and Bernardi et al. (2018) state that traffic lights are preferred because they provide a safe option of crossing a road compared to crossing a road without traffic lights.

Busy roads in Amsterdam are avoided by children due to safety concerns (Dessing et al., 2016). Similarly, according to Parkin, Wardman & Page (2007) busy roads increase perceived risk, resulting in cyclists' avoidance of busy roads. Bicycle lanes do have a favourable impact. However, the impact is not significant enough to decrease the perceived risk of motorized traffic. Remarkably, parked vehicles on a busy road do not seem to impact cyclists' route choice. Aldred & Dales (2017) confirm that in London, many cyclists detour to avoid busy roads due to perceived safety concerns. Cyclists prefer to cycle along more traffic calming facilities and prefer residential roads to arterial roads that are busier (Winters et al., 2010; Krenn et al., 2014; Verhoeven et al., 2018). According to Vedel, Jacobsen & Skov-Petersen (2017), a busy road and interruptions cause people to choose another route. This is confirmed by Menghini et al. (2010) and Foster, Panter and Wareham (2011), who state that cyclists tend to avoid busy routes and traffic lights. Moreover, Hochmair (2005) identified 'avoid heavy traffic' as an important criterion for route choice. Adversely, de Geus, de Bourdeaudhuij, Jannes & Meeusen (2008) and van Dyck et al. (2012) determined no association between busy roads and attractiveness for cycling.

2.3 Influence of personal characteristics

Previous research has shown that personal characteristics influence route choice of bicyclists. Indicators previously used in research are age, gender, automobile ownership, cycling experience, reasons of cycling, household size, household income, education/employment level, commute distance and work schedule flexibility (Atonakos, 1994; Aultman-Hall, 1996; Hopkinson & Wardman, 1996; Ortúzar et al., 2000; Howard & Burns, 2001; Stinson & Bhat, 2003; Tilahun, Levinson & Krizek, 2007; Sener et al., 2009; Dane et al., 2019). These indicators can be divided into three categories: demographics, bicycle use and employment. The influence of the green environment differs for all categories. These dissimilarities in influences are interactions, for example whether male and female bicyclists experience a dark dike in the same manner or not. Based on previous research, female bicyclists avoid dark areas more than men due to safety concerns (Xie & Spinney, 2018). Other interaction effects are described below.

2.3.1 Demographics

Related research on the influence of demographics on route preference is dominated by the personal characteristics age and gender. Moreover, there is no consensus on the influence of demographics on route preference. This section will consider different demographics and their possible influence on route choice behaviour.

Age

Much research agrees that age is indicative of route preference, where for example increasing age is negatively associated with route distance (Dane et al., 2019; Stinson & Bhat, 2003; Ortuzar, Iacobelli, & Valeze, 2000). According to Tilahun et al., (2007), age is indicative of route preference based on environmental factors. Westerdijk (1990) states that in addition to age being significant to route preference, the route preference can be specified in that pleasantness of the route is more valued by older people than younger age groups. Additionally, Antonakos (1994) notes that age is negatively associated with preference for variables of the green built environment, both for recreative cycling and commuting. Ma & Dill (2015) add that compared with people aged 35-54, younger people see high bikeable built environments with much green as more bikeable whereas people aged over 55 years perceive the high bikeable built environments as low bikeable. Moreover, Steer Davies Gleave (2012) found that people above 55 years of age possess a greater willingness to change their route for parks and green spaces; 67% compared to 58% of 35–54-year-olds, and 47% of under 35-year-olds.

Winters & Teschke (2010) disagree and specify that age in general is not a significant predictor of route choice preferences. This is confirmed by Mertens et al. (2014), who note that there are no moderating effects of age when exploring variables of the green built environment related to invitingness for cycling.

Sex

Tilahun et al. 2007 state that sex is less indicative of route preference because sex was not significant for the probability of choosing a higher quality route. Tin et al. (2010) agree that men and women rate bicycle paths in a similar manner. Westerdijk (1990) found that even though there are some differences between male and female cyclists when valuing distance, pleasantness and traffic safety of a route, the differences are not significant. This is confirmed by Mertens et al. (2014), who note that there are no moderating effects of sex when exploring variables of the green built environment related to invitingness for cycling.

Adversely, Brick, McCarthy, & Caulfield (2012) found that female cyclists have a greater preference for greenways and off-road cycle lanes than male cyclists. Heesch, Sahlqvist & Garrard (2012) confirm that women rather cycle off-road through a green environment whereas men prefer to cycle on-road. In contrast, Gardner (1998) notes that females are less willing to cycle in parks or in the countryside due to social safety concerns. Van Holle et al. (2014) evaluate safety as well, where associations with invitingness for cycling are found in female bicyclists whereas they are not significantly related to male cyclists. Tilahun et al. (2007) add that females are willing to cycle further in order to ride along a preferred facility. Vedel et al. (2017) confirm that female bicyclists in Copenhagen are willing to cycle up to 1.07 kilometres further from the shortest path to achieve a route with green surroundings.

Household size and income

According to Tilahun et al. (2007), household structure is indicative of route preference because in households with more than two persons, the chance of choosing a better quality with longer travel time route is lower than those with two persons or less in their household. This is probably due to time constraints being higher on multiple person households. Conversely, household income is less indicative of route preference, even though a higher income raises the probability of choosing a more beautiful but longer route. Stinson & Bhat (2003) disagree and state that households with a low income are less sensitive to route preference, thus more often taking the shortest route. According to Ortúzar et al. (2000), households with a low income cycle more often than households with a higher income due to the low cost that a bicycle requires compared to other transport modalities.

2.3.2 Bicycle use

Automobile ownership

Antonakos (1994) states that the possession of a car has no significant effect on route preference. Ortúzar et al. (2000) disagree and describe the effect of automobile ownership on willingness to cycle as positively significant. This is confirmed by Fu & Farber (2017), who note that car ownership has a significant negative impact on bicycle use and is associated with less frequent cycling than people who do not own a car.

Cycling experience

The more experience a cyclist has, the more attractive a route looks to a cyclist. Cyclists who are just starting to cycle are prone to rate a route lower than cyclists who have more experience (Axhausen & Smith, 1986). Furthermore, Hunt & Abraham (1996) confirm that the attractiveness of a route increases as cycling experience on it does. Hopkinson & Wardman (1996) state that cycling experience has a significant effect on route preference, whereby risk reduction remains most important for cyclists.

Reasons of cycling

The reason that people cycle influences their route preference. Ortúzar et al. (2000) state that cycling is more often related to commuting to work rather than cycling for leisure. Therefore factors such as distance and time are more important than the aesthetic of a route. Hopkinson & Wardman (1996) find that people cycle more often for leisure rather than commuting to work. The reason people cycle to work is that it is better for the environment, their health and because it is enjoyable and cheaper than other modalities. Adversely these motivations have no influence on route preference. Vedel et al. (2017) state that the reasons for cycling are divided based on whether people possess a car or not; if people have a car, their main reason for cycling is exercise. Respondents who do not own a car cycle primarily because it is cheap. Exercise is a less important reason. This influences route preference because exercising is positively associated whereas a cheap modality is not.

Another influence is peoples' attitude towards cycling. People who love greenery will be more willing to cycle with more cost, for example more distance, than people who do not care for greenery (Karanikola et al., 2018). Other attitudes are important for cycling as well. Bonham and Koth (2010) found that health, affordability, environmental concerns, and pleasure are main reasons for cycling. People who cycle for health and pleasure are expected to prefer to cycle through a green environment rather than along a noisy highway (Nawrath et al., 2019; Zijlema et al., 2018).

2.3.3 Employment

Education or employment level

Ortúzar et al. (2002) state that people with a low educational level cycle more often than people with a higher education. It affects route preference in the sense that getting to work on time is the most important goal of the trip, thereby removing the scenery of the route as a factor and focusing on fast flow of the route instead. Commuting by bicycle is perceived as embarrassing since only blue-collar workers cycle. This may be applicable to foreign countries, however in the Netherlands educated people cycle more than less educated people (Harms, 2006; Pelzer, 2010). Moreover, people with high-level employment bike more often to work in the Netherlands and use their route as an opportunity for an outing (Harms, 2006). This implies that factors such as scenery and beauty of the route are important.

Distance of trip

Tilahun et al. (2007) show that people are willing to cycle 20 minutes to switch between a road with no facilities to an off-road cycling trail, which means that they are willing to cycle 20 minutes further in order to be surrounded by greenery during their trip. Vedel et al. (2017) agree with the sentiment, finding that people are willing to cycle 0.8 km further to be able to cycle trough green surroundings. However, stated preference studies reveal that people do not often divert from the shortest route (Mengheni et al., 2010; Broach et al., 2012).

Chapter 2 discussed the literature review of this study. Related research has indicated several methods of identifying the relationship between cycling and the built environment. Moreover, it answers the question of what spatial indicators of the green built environment according to literature are. This literature review has highlighted the indicators greenery and water, aesthetics noise, and busy roads and traffic lights. Furthermore, possible interaction effects of personal characteristics have been discussed. The review demonstrates a research gap between the influence of the environment in relation to the urbanity of the environment because the highlighted studies were predominantly executed in an urban context. Chapter 3 will describe the preliminary study, where distinguishing indicators revealing the influence of built environment on route preference in the Netherlands is the focus by performing ride-alongs in the city of Zwolle.

3

Preliminary study

Chapter 3 discusses the preliminary study that was executed in order to find indicators of the built environment that people consider when choosing their cycling route. It answers the preliminary sub question ‘What are spatial indicators of the green built environment according to bicyclists in Zwolle?’. The preliminary study adds to the quantitative research in this project because quantitative research primarily tests variables that are determined based on the literature review. However, route choice decisions in the real world are influenced by multiple unexpected aspects. The preliminary study is an explorative study, where rather than starting with variables retrieved from literature, there are no determined variables at the start of the research. Variables are determined based on the experience of cycling together with commuters and identifying their motivations for choosing a route. In order to identify these aspects and value their worth as an indicator, ride-alongs were performed in the city of Zwolle.

A ride-along is an interview method where the participant can be observed in their physical and social environment. The researcher asks questions, listens, and observes the participant (Kusenbach, 2003; Adekoya & Guse, 2020). Ride-alongs are chosen over normal interviews because ride-alongs generate data about the relation of participants to their environments (Evan & Jones, 2011).

The preliminary study was performed in Zwolle because the city provides extensive options for cycling, including a separate bicycling infrastructure. Additionally, Zwolle has a higher cycling percentage than the national average (Heinen, Maat & van Wee, 2011). Therefore, it is to be assumed that Zwolle’s cyclists are representative for Dutch bicyclists, especially in an urban context.

The explorative study required at least 15 participants from different age groups and social classes. Sample sizes are a compromise between the constraints of time and cost, the need for precision (Bryman, 2012; p. 197). The number of 15 is chosen as the preliminary study is shaped as a crossover between a focus group and an in-depth interview. The recommended size for a focus group is 6-8 persons (Bryman, 2012; p.507), whereas a sample size for in-depth interviews is recommended at 20-30 participants (Bryman, 2012; p. 426). Therefore, 15 has been chosen as a medium between the two examples. The ride-alongs were performed on routes that participants were cycling to their destination. The ride-alongs took place in week 43 of 2020 in the Region of Zwolle. Out of the 28 people approached for this preliminary study, six agreed to participate. Other participants were determined by snowballing trough the original six participants; either neighbours, friends, classmates, or acquaintances that were present at the destination of their route, whereafter the participants informally introduced the study and established goodwill. This approach resulted in 17 participants. Table 1 provides the distribution of participants concerning age and sex. Notes per route are available in appendix A.

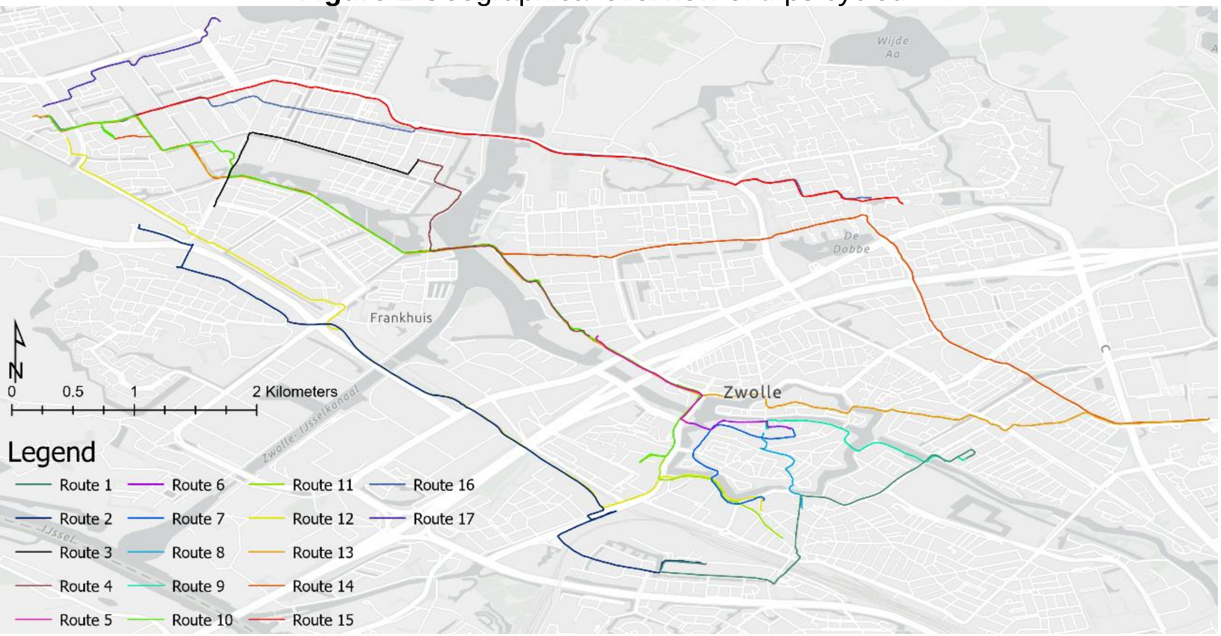
Table 1 Participant characteristics

	Male	**Female**
<20 years	3	3
20-45 years	4	3
>45 years	2	2

The interviews during the ride-alongs were semi-structured. Upon the introduction, the destination of the participant is requested. Moreover, preferences for cycling were inquired before the start of the trip. During the ride, the participant talked about their route choice, their preferences and their aversions related to the built environment. The answers to both questions and their remarks during the route provide the foundation for the determination of indicators for the analysis, as described in section 4.1.

The maximum duration of the trips was 45 minutes. With regard to the distance, the shortest trip was 0.63 kilometres, whereas the longest trip was 7.61 kilometres. The average trip length was 3.35 kilometres. The shortest trip seems very short, however the city centre of Zwolle is small compared to other Dutch cities and the trip took place between two utility services. Figure 1 provides an overview of the trips. In order to protect the privacy of the participants, the first or last 100 metres are removed from the trip so that origin and destination are not traceable to home addresses.

Figure 1 Geographical overview of trips cycled



Source ESRI, HERE, adapted by author

3.1 Indicated preference

The start of each trip was characterized by an assessment of the indicated preferences. Participants were asked the open question "What do you keep in mind when choosing your cycling route? Further prompting was not necessary. The indicated preferences can be divided into six categories; experience, infrastructure, traffic and noise, aesthetics, green environment and water, and fast flow. Table 2 provides an overview of the indicated preferences in this study classified by the categories. Similar indicators such as 'cycling along mansions' and 'cycling next to beautiful manors along the canals' are approached as one indicated preference indicator. Furthermore, the indicators are shaded according to enjoyment and annoyance, where green signifies a positive association, orange signifies a neutral association and red a negative one.

Table 2 Indicated preferences retrieved from interview at start of trip

Experience	Infrastructure	Traffic and noise	Aesthetics	Green env. and water	Fast flow
Feel the sun and the weather	Cycling separately from cars	Cycle along the train tracks	Pass cafes	Cycle along greenery	Find fastest traffic flows
Combining trips; visit shops during route	Cycling through the 'fietsstraat'		Cycling along the historic city walls	During business hours, pass the dike	Fastest route in the morning
Prefers trees over street lighting	Cycling path rather than residential street		Cycling along the Sassenpoort	Cycle along water	Shortest commute
Find open space in case of sun	Wide cycling paths		Cycling along the mansions	Take as many bridges as possible	
Pass the petting zoo and their sheep			Cycling along houseboats	Cycle along the canals	
Pass supermarket			Cycle along the canal	Scenic path in the evening	
Cycling beneath street lighting			Cycle trough part of the city centre	Pass trees for shelter	
Cycling along creative spaces				Pass football fields	
Enjoying the ride				Cycling through forests	Avoid pedestrian areas
Open, creative, or lively places				Cycling through a park	Avoid schoolchildren
Avoid trees due to hay fever	Avoid tunnels	Avoid cars	Avoid boring routes		Avoid city centre
Cycles trough residential areas when it is windy	Usually avoids residential areas due to curbs to slow car traffic	Avoiding cars leaving the parking garage	Avoids residential areas		Avoid people walking over cycle path
Avoid open space in case of wind and rain	Avoids streets without separate cycling tracks	Avoid big intersections with cars			Avoid tourists and pedestrians
Avoid double timing roads	Avoid traffic lights	Avoid cars			Avoid business in general
	Avoid road work				Avoid slower cyclists
					Avoid cycling parents with kids
					Avoid obstructions
					Avoid schoolchildren

3.2 Observed preference

After the determination of the indicated preferences, the observed preferences were noted during the route. During the trip, questions were asked in case participants were not immediately forthcoming about their choices during the route by asking them why they choose this exit rather than the next one for example. Since the route is determined by the participant, no influence was performed there. Additionally, even though it was never indicated after the question at the start of the route that people were required to talk about their route and their motivation for choosing it; every participant did. Table 3 provides an overview of the observed indicators during the ride. Many records have been shortened to enhance the readability of the table and the usefulness of the indicator.

Table 3 Observed preferences during cycling trips

Experience	Infrastructure	Traffic and noise	Aesthetics	Green env. and water	Fast flow
Preference of exclusivity	Preference for 'Fietsstraat'	Preference for shortcuts between buildings	Preference for nice buildings and cityscape	Preference for very green verges	Preference for fast traffic flows
Prefers elevation differences	Preference for bridges	Cycling bridge preferred to walking bridge with bike grooves	Bridges are seen as aesthetic	Preference for cycling along water	Preference for fastest route heading somewhere
Habit	Wide cycling paths preferred over narrow ones		Preference for wide views	Preference for cycling along/in the park	Preference for taking pavement to shorten route
Preference for chirping birds	Preference for dwindling roads	Not much avoidance of dangerous intersections	Preference for landmarks	Preference for cycling along the dike	Acceptance for noise when route is fast flowing
Preference for liveliness	Preference for residential areas when weather is bad		Preference for diverse sights	Preference for trees along the route	Fastest commute
Sense of superiority over cars	Preference for separate cycling paths rather than cycling paths on the road	Avoiding busses	Preference for diverse urban development	Preference for dike rather than residential area	
Cycling as an outing	Both preference and avoidance of cycling through pedestrian areas	Avoidance of car noise	Awareness of development of built environment	Preference for cycling along canals	
Positive mental effect of cycling	Avoidance of tunnels	Avoidance of highway noise	Preference for monuments	Preference for passing a forest	
Combining trips	Avoiding residential streets	Avoidance of curbs in residential areas	Beauty of the route	Preference for green separation of the highway	
Route provides joy	Avoidance of parked cars	Avoidance of dark tunnels due to echo	Preference for pretty lights overhead		
Preference for diversity of the road	Preference for street lightning	Avoidance of having to cycle distances double	Preference for art close to the route		
Use of secured bicycle facilities	Avoidance of nearby cycling path due to distance to exit	Avoid traffic			Avoidance of pedestrians
Preference for cafes	Avoid traffic lights	Avoiding playing children		Avoidance of Oak trees in spring due to the oak processionary caterpillar	Avoidance of obstruction
Weather and sun were felt	Avoiding road work	Avoidance of cars	Avoidance of boring routes	Avoidance of green after dark	Avoidance of slower cyclists

3.3 Analysis

Table 2 and Table 3 provide an overview of the results of the ride-alongs. The differences between indicated and observed route preferences vary per category, however there are few contradictions. The differences are detailed per category.

3.3.1 Experience

The indicated preferences for experience are primarily focused on the weather, positive psychological effects of the route and the ability to combine purposes on a bicycle trip, whereas the observed preferences add to the list with a feeling of exclusivity, superiority, the impact of habit, the desire for experiencing nature and a sense of challenge in elevation difference.

3.3.2 Infrastructure

The category infrastructure is similar. The indicated preferences are avoiding cars, tunnels, traffic lights, residential areas and actively choosing separate cycling paths or the 'fietsstraat'. The observed preferences add insight into the reason that residential areas are avoided; namely curbs, parked cars, and mixed traffic roads. Contrary, residential areas are used as shelters from the weather and the dark. Moreover, bridges are preferred over tunnels and pedestrian areas are both avoided and used for shortcuts.

3.3.3 Traffic and noise

Traffic and noise yield that cars, children and other distractions on the route are avoided, both because of their noise and their interrupting effect on the cycling route. Remarkably, the indicated preferences seem to avoid big intersections with cars whereas the observed preferences avoid intersections only slightly. Moreover, even though participants actively avoided noise, its presence is tolerated for a shorter route alternative. Overall, traffic and noise are avoided but tolerated for time saving.

3.3.4 Aesthetics

The category aesthetic yields similar results for indicated and observed preferences. Overall people tend to avoid a route with similar sights and environment, also named as boring routes. They prefer landmarks, monuments, liveliness, art and pretty lights, bridges, and beauty in general instead.

3.3.5 Green environments and water

Green environments and water bodies is an interesting category. Predominantly, people prefer green surroundings and water along their route. Based on the indicated and the observed preference, people choose the fastest route on the way to their destination whereas on the way home, scenic features such as dikes and parks are motivation for a longer, dwindling route. That is not to say that route to destinations do not enter green environments, on the contrary even, but people are less willing to divert from a fast route. Green verges, parks, forests, dikes, water, and bridges are part of every route but one cycled in the preliminary study, both indicated and observed. On the other hand, green surroundings and water are avoided in the dark and during harsh weather conditions due to safety concerns.

3.3.6 Fast flow

Finally, the fast flow of a route is important. People actively avoid slower traffic participants and obstructions. Furthermore, wide cycling paths are favoured because overtaking other cyclists is easier there. The city centre and other pedestrian areas are avoided unless they can provide an illegal shortcut. As explained previously, faster routes are more important on the way to a destination other than home than on the way home in this preliminary study.

Chapter 3 provided the results of the ride-alongs in Zwolle. Together with Chapter 2, it provides the foundation for the conceptual model that will be presented in Chapter 4. Moreover, it answers the preliminary sub question '*What are spatial indicators of the green built* *environment according to bicyclists in Zwolle?'*. According to the preliminary study, indicators of the built environment are to be divided into six categories; experience, infrastructure, traffic and noise, aesthetics, green environments and water, and fast flow. Each category contains its own indicators, which will be detailed extensively in Chapter 4. Chapter 4 describes the conceptual model and methodology of this research, where distinguishing the influence of built environment and personal characteristics on cycling is the focus.

4

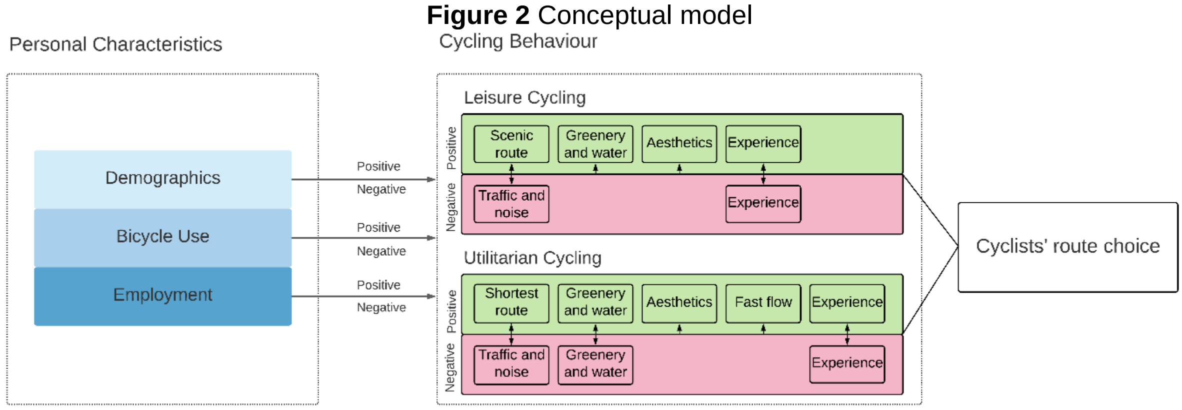
Conceptual model and methodology

In this Chapter, the data, the methods, and analysis that take place to create the results are discussed. First the conceptual model of this study is considered. Since the conceptual model was derived from both Chapter 2 and Chapter 3, it was decided to include it in this chapter. Thereafter the research area is described in section 4.2, after which section 4.3 discusses existing data necessary for this research. The research methodology is then explained in section 4.4.

4.1 Conceptual model

Figure 2 shows the conceptual model of this research. It provides a representation of the expected causal relationship, where expected indicators of the green built environment and personal characteristics influence route choice of bicyclists. The indicators of the green built environment are selected based on the findings of Chapter 2 and Chapter 3. The individual characteristics are divided into three categories; demographics, bicycle use and employment characteristics as discussed in Chapter 2. For the personal characteristics, the arrows provide the expected correlation between the subjects. The cycling behaviour subjects are drawn in the red box when their expected influence is negative, whereas expected positive influences are put in the green boxes.

Figure 2 Conceptual model



The indicators of the green built environment influence cyclists route choice either positively, negatively or do not influence route choice at all. The expectation is that there is a difference between cycling for leisure and cycling for utilitarian purposes such as cycling to work or school. In the case of cycling for leisure, it is to be expected that people prefer a scenic route so that they can appreciate the view. Moreover, greenery and water are expected to have a positive impact because greenery and water relaxes people and improves both self-esteem and mood (Barton & Pretty, 2010). Furthermore, aesthetics is expected to be a positive influence because the literature review has shown a positive effect. However, this review is not unanimous since Kondo et al. (2009) found no significant relation between aesthetic and the attractiveness of a cycling route. Experience can be both a positive and negative influence. In case the weather is good, the chance of people choosing an alternative route than the shortest is greater than in bad weather. Traffic and noise are expected to be a negative influence since both the qualitative preliminary study and the literature review indicate that its influence is in fact negative.

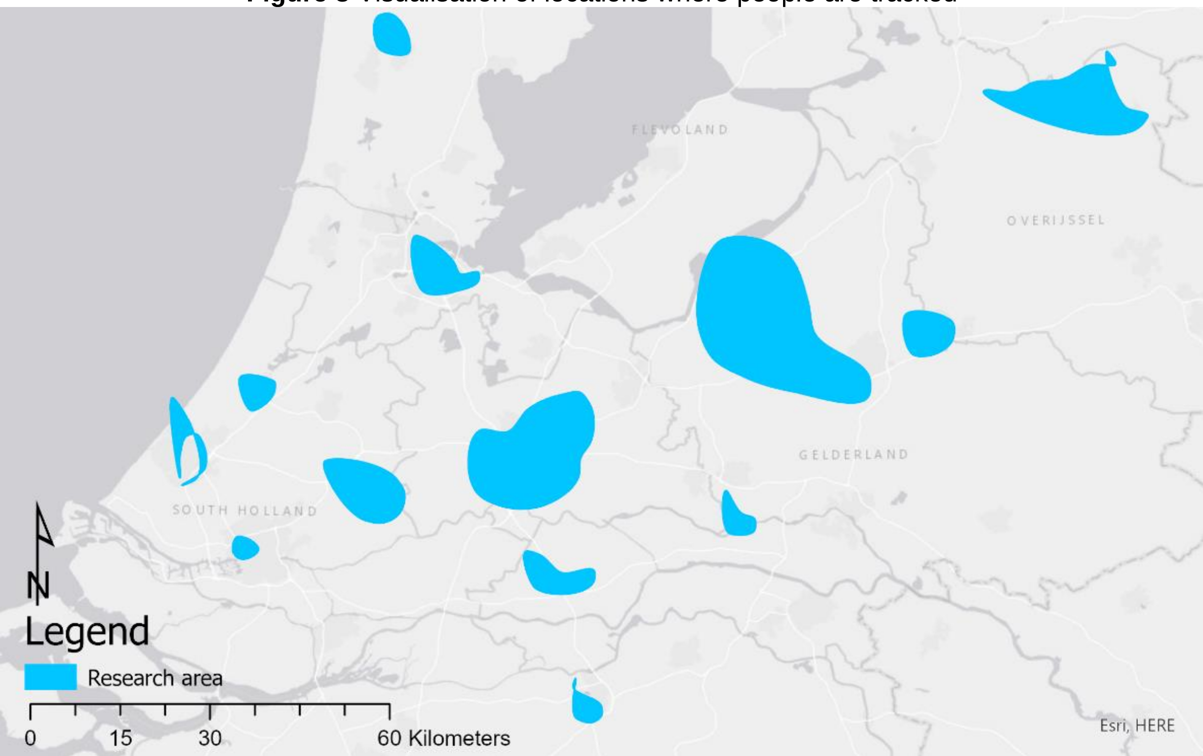
Cycling for utilitarian purposes provides a different point of view on the influences than cycling for leisure. Rather than enjoying the scenery, most of the focus of utilitarian cyclists is on the minimization of costs. For cycling, minimizing the cost translates to minimizing distance (McFadden, 1975). This means that the shortest route has a positive influence on route choice. Fast flow has a positive effect as well, as shown in both literature and the preliminary study. Greenery and water are expected to be positive for the same reasons as they are for leisure cycling. However, greenery and water can also be a negative influence on utilitarian cycling, namely if they add distance to the shortest route. In addition, greenery and water can cause barriers, requiring people to cycle around a park or along the waterfront in order to reach a crossing which is expected to be valued more negative than in the case of leisure cycling. Experience poses a similar contrast. The preliminary study indicated that people are prone to choose different routes varying on the weather and on liveliness along the route. Traffic and noise are expected to be a negative influence similar to leisure cycling.

Personal characteristics influence cyclists' behaviour as well. The expectation is that the individual characteristics exercise a variation of positive or negative influences, depending on the characteristic. For example, age has a negative influence on route distance, whereas cycling experience has a positive influence (Dane et al., 2019; Hopkinson & Wardman, 1996). Nevertheless, the influence of the personal characteristics variables will vary from previous research since this study takes place in the Netherlands, a country with a cycling culture wholly different from the rest of the world (Holligan, 2013).

4.2 Research area

The research area of this study consists of the Dutch provinces North Holland, South Holland, Utrecht, Gelderland and Overijssel and the city of Den Bosch. The research area consists of both rural and urban areas based on the home locations of the volunteers who were willing to be GPS tracked. An attempt was made at selecting one urban and one rural research area, however this was not feasible since a representative data sample required more participants.

Figure 3 Visualisation of locations where people are tracked



Source ESRI, HERE, adapted by author

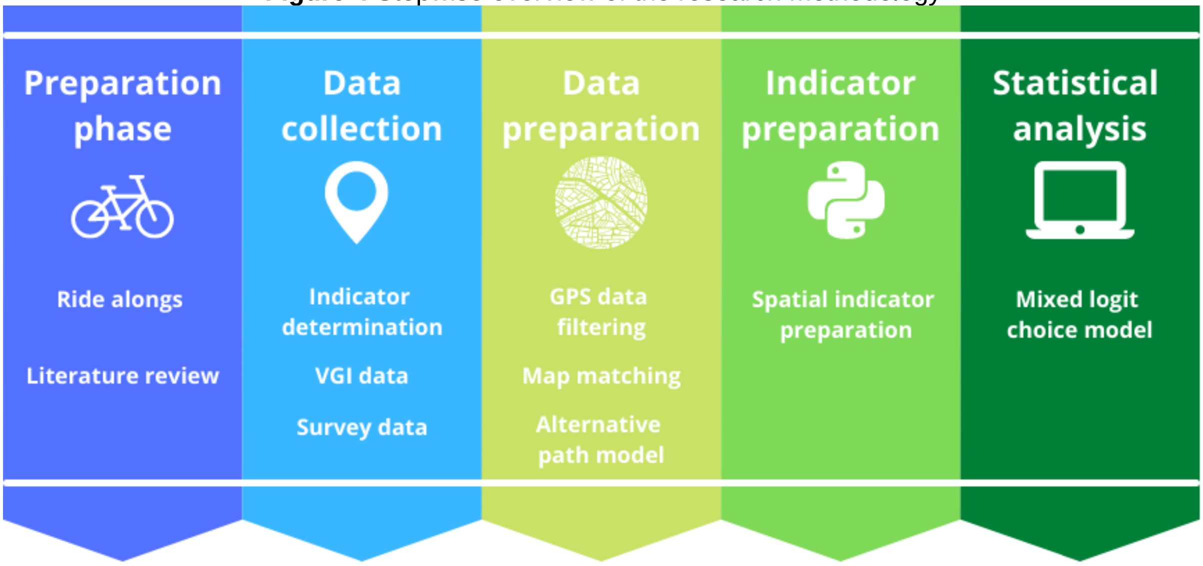
4.3 Software

Each step of the research methodology requires different software. An important thing to keep in mind is that the data retrieved from the GPS trackers contains both a spatial and a temporal dimension. All programs are thus required to be able to handle such data. In this research project, the programs QGIS, ArcMap 10.7, ArcGIS Pro and Stata are used. ArcGIS Pro is explicitly designed for the handling of spatial data, which is needed for the spatial analysis that will be performed in this study. ArcMap 10.7 is used for the creation of the shortest path model since the program has a pre-built set of route determination options. Finally, Stata is used to create a conditional logit model in order to determine the influence of the indicators of the built environment on route choice.

4.4 Methodology of the research project

Figure 4 provides an overview of the research methodology of the research. Chapter 2 and 3 discussed the preparation phase with the literature review and the research methodology of the explorative preliminary study.

Figure 4 Stepwise overview of the research methodology



Since the preparation phase has been completed, the methodology can be divided into four stages: data collection, data preparation, indicator preparation and the statistical analysis. Data collection consists of the research steps determination of indicators and VGI- and survey data collection. VGI is an abbreviation for Volunteer Geographical Information. It encompasses finding a method in order to create, assemble, and disseminate geographic data provided voluntarily by individuals (Sangiambut & Sieber. 2016). In this study, it is the tracking of bicyclists. Data preparation consists of the steps map matching, creation of the shortest path model, isolate route segments and observed paths and shortest paths. The indicator preparation phase is a single step, after which the statistical analysis is executed in the analysis phase. After the analysis, the results are interpreted in order to answer the research question.

The data preparation and indicator preparation phase are performed together with two other students, to ensure enough volunteers are being tracked to create a representative data sample. Additionally, map matching is a demanding process and splitting the workload enables the research project to be carried out within the available time.

4.4.1 Data collection

Determination of indicators

Both the literature review as well as the preliminary study provide possible indicators of the built environment. The indicators for the built environment that are applicable to this research are identified in this step of the research methodology. The identification of the indicators is based on the rules in Table 5. In case an indicator is just present in literature, it is not automatically taken as an indicator of the built environment as much of existing research has been performed outside of the Netherlands. Due to the difference in cycling infrastructure and bicycle culture, it is important that variables are confirmed during the preliminary study in Zwolle. In case an indicator is present in the preliminary study but not in the literature review, a threshold value of at least 20% of the participants is adhered to in order to prevent unique personal preferences.

Table 4 Determination of indicator

Rule	Indicator
Indicator is present in both literature review and preliminary study	Yes
Indicator is only present in literature review	No
Indicator is present in preliminary study by more than 3 participants	Yes
Indicator is present in preliminary study by less than 3 participants	No

Since not all of the findings of the literature described in Chapter 2 are applicable in the Netherlands, Chapter 3 provided the findings of the explorative case study in Zwolle. Table 6 provides the indicators combined from both Chapters. The indicators are sampled based on the rule of determination of indicators, as described in Table 4.

Table 5 Possible variables of the green built environment

Experience	Infrastructure	Traffic and noise	Aesthetics	Green env. and water	Fast flow
Combining trips	Separate cycling paths	Intersections	Landmarks	Green verges	Pavements/ shortcuts
Weather	Tunnels	Traffic	Sightlines	Parks	Uninterrupted roads
Liveliness	Bridges	Noise	Monuments	Forests	Obstruction
Mental effects	Street lightning		Urban development	Levee	
Habit	Traffic lights		Art	River	
Daylight	Pedestrian areas			Canals	
	Residential areas				

The indicators in Table 5 are in abundance. Moreover, not all of them are quantifiable. Therefore, the indicators have been sampled down to a maximum of two per category. Out of the category experience, just weather, daylight and liveliness are quantifiable. The weather, in this case precipitation, and daylight are recovered from KMNI weather stations, whereas liveliness is harder to quantify. In this study it could be measured by the amount of people in the street and the presence of art and culture. However due to corona, people are encouraged to stay at home and art and culture in the form of markets, public events and festivals are not visible on the street anymore. Therefore, the indicator is left out. The category infrastructure is narrowed down to street lighting and bridges. Street lighting is selected because both literature and the preliminary study showed that the presence of street lighting affects route choice in green areas and bridges because the preliminary research found that people prefer bridges over tunnels and they are usually close to water. Therefore, tunnels are not taken into account as an indicator. In a similar fashion, pedestrian areas and residential areas are not considered because these areas are not measured by undisputable boundaries. Street lighting and bridges are both enclosed in the information in the Fietsersbond network. The category traffic and noise is removed since it correlates with safety. Aesthetics brings monuments, art, and landmarks together in the variable aesthetics since all are characteristic of the landscape. This indicator is derived from the Fietsersbond network as well. Green environment and water is narrowed down to greenery and water, where greenery consists of green verges, parks, forests, and levees whereas water consists of rivers, canals, and other water bodies. Fast flow is determined by obstruction since uninterrupted roads are dependent on many factors. The information on obstruction on a road segment is derived from the Fietsersbond. The determined variables of the green built environment are ordered in Table 6.

Table 6 Variables of the green built environment

Experience	Infrastructure	Traffic and noise	Aesthetics	Green env. and water	Fast flow
Precipitation	Bridges		Aesthetics	Greenery	Obstruction
Daylight	Street lighting			Water	

Since the spatial analysis requires source data that identify the location of indicators of the built environment and their relation to the routes retrieved from the VGI data, the data for the spatial indicators must be retrieved from different sources. Table 7 provides an overview of data necessary for the analysis based on the variables of the green environment.

Table 7 Required dataset and source

Dataset	Source
VGI data	GPS trackers
Bicycle network	Fietsersbond
Water	Fietsersbond
Green areas	Fietsersbond
Precipitation	Royal Netherlands Meteorological Institute (KNMI)
Street lighting	Fietsersbond
Bridges	Key register Large-scale Topography
Daylight	Royal Netherlands Meteorological Institute (KNMI)

VGI- and survey data collection

Sample

The sample of this research project consists of volunteers in the research area who are approached by the researchers. This means that there is a bias in the participants, because all participants are associated with the researchers. Regulations regarding covid-19 prevent meeting multiple people per day and visiting people in their homes to explain the tracking process. Moreover, the willingness of people to let students in their home is very low. The sample is not random, since people who are familiar with the researcher are more willingly to welcome them into their house in order to explain the tracker and the tracking process. This study thus uses convenience sampling (Etikan, Musa & Alkassim, 2016).

Each participant carries a GPS tracker for the duration of seven days, providing the option to recognize weekly patterns. However, this means that a number of trips in the dataset are correlated because routes are cycled by the same participant. The fraction of variance unexplained, or the fraction that is not correctly predicted, will thus be similar for a number of trips. This impediment is recognized. Another concern is the decrease in cycling trips because of covid-19. Nonetheless, due to the time constraints of this thesis, the research sample is not according to sample standards of statistical analysis. However, the researchers have endeavoured to create a sample that approaches statistical sample standards (Selby et al., 2018).

VGI data

The use of VGI data is not without concerns. Mooney et al. (2017) raise concern about privacy, ethics and legal issues when using VGI. As accuracy is important for the geographical component of the collected geographical data, data can be traced to individuals, which means that the data can be used to infer other information about the individual. There are several approaches to ensure privacy of participants; among which fuzzing information (Luther et al., 2009) and selectively revealing information (Kim, Mankoff & Paulos, 2013). This does however reduce the reproducibility and the replicability of the study. Anonymity should not just be applied to data retrieved from humans, but for data retrieved from non-human subjects as well (Mooney et al., 2017). Ethical concerns are mentioned with regard to both the researcher and the participant. The researcher should preserve the privacy and dignity of the participant, whereas the participant should preserve the integrity of the dataset. Legal issues emerge regarding intellectual property and liability. The researcher possesses ownership rights of the data, whereas the participant pertains the right to disseminate and enrich the data (Mooney et al., 2017). Liability is a cause of concern because of the different data licences the researcher can instate. An open data license could damage the privacy of the participants. These concerns have to be kept in mind during the study. The privacy issue is mitigated due to the aggregation of spatial data for the choice model input, thereby concealing participants' home address. Additionally, maps in this thesis do not show routes from participants who did not provide permission to share their routes. The participants receive a letter detailing the anonymisation process and instructions for handling the tracker. The letter is enclosed in Appendix B.

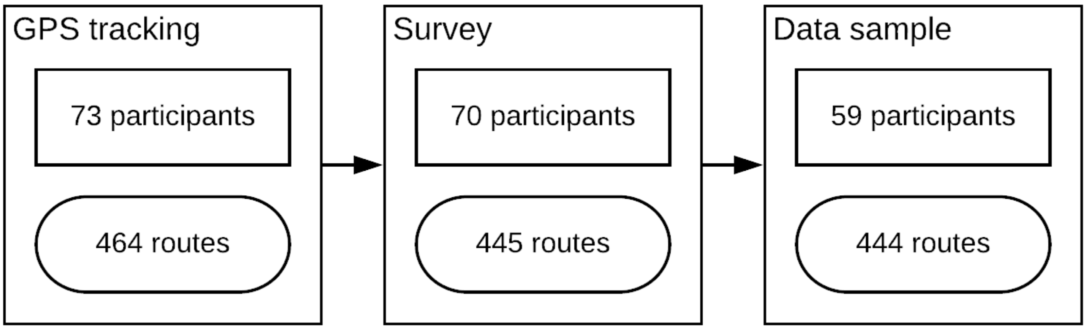
Moreover, the applicability of GPS tracking to bicycling can be questioned. The accuracy of the Global Positioning System is approximately 10 metres (Bothe & Maat, 2009), which is more than the width of a cycling path. Bohte & Maat (2009) state that by using GPS trackers, the accuracy of VGI data is significantly higher than traditional methods, resulting in the conclusion that GPS tracking is applicable to bicycling research. Adversely, the number of participants is expected to be lower than in a study when smartphone tracking is used (Pritchard, 2018). This needs to be taken into account while reaching out to possible participants. However, GPS tracking is preferable to smartphone tracking in this study due to the minimal burdening of the participant; their phone will not be drained due to the constant tracking and the guaranteed continual tracking. Contrary to the GPS trackers, smartphones will stop an app that drains its battery, thus not ensuring continuous tracking. During the GPS-tracking, participants were required to charge their GPS-tracker after each use. Participants forgetting to charge their GPS led to missed route tracking. Moreover, two GPS tracker lost signal during the tracking phase, resulting in a set of missed GPS data.

Survey

In addition to the GPS tracking, volunteers were be asked to fill in a survey. The survey is provided in appendix C. The survey is in Dutch, since all participants are Dutch. For this study, the questions on the survey reveal the indicated preference of the participants. They are asked which indicators of the built environment influence their route choice positively or negatively based on statements which are answered with a Likert scale. Therefore, the survey is provided after the participants are tracked, thereby minimising the chance of influencing bicycling behaviour.

To conclude the data collection, Figure 5 provides an overview of the number of participants and the subsequent number of routes that have been retrieved and generated. Routes are only admitted to the dataset when both GPS tracking is performed and the survey is completed. A few GPS trackers malfunctioned, sending no GPS points to the database. The 464 routes are routes that were stored in the point database. The final sample thus consists of 59 participants who cycled a total of 444 routes.

Figure 5 Sample overview



4.4.2 Data preparation

Data filtering and map matching

The VGI data collection results in a database with GPS points. These points have to be separated based on cycling movements and subsequently matched to a base map to create a route. The retrieved VGI data is one big file of separate points per day. These tracks are separated into moments when people ride their bicycle and the rest of their movements during the day. This separation is performed based on the speed of movement during migrations. In this research, cycling is the only relevant mode of research. The average cycling speed in the Netherlands is 15 km/h (Fishman, Böcker, & Helbich, 2015). Motorized vehicles average 48 km/h, whereas walking averages 5 km/h (Huss, Beekhuizen, Kromhout & Vermeulen, 2014). Furthermore, the lowest speed restriction on public roads is 30 km/h for motorized traffic.

Bohte & Maat (2009) use a decision tree to determine mode of transport. Cycling is determined as the mode of transport if the average speed is between 10 and 24 km/h and the maximum speed is between 15 and 44 km/h. These speed boundaries determining cycling may display similar speed profiles to jogging, however jogging is rarely used for commuting and people generally do not take much with them while jogging so it is to be assumed that they will leave their GPS at home, therefore it is less of an issue when determining mode of transport (Huss et al., 2014). Since 2009, the sale of e-bikes has risen; thereby increasing the speed of cycling. E-bikes in Australia average continuous speeds of at least 25 km/h throughout their range when operating in assist mode (Allan, 2016; p.1). Eenink (2018; p.36) confirms that the average speed of e-bikes in the Netherlands is 25 km/h. Limiting the upper speed boundary would exclude e-bikes cycling above average speed, therefore it is assumed that all tracks averaging a speed between 10 and 29 km/h are tracks that were cycled. The python script that separates GPS points into routes based on speed is enclosed in appendix D.

After the separation of GPS points into different route movements, the GPS points are map matched to a network to create observed cycling routes. In this study, the base map is the road network map provided by the Fietsersbond. This process is known as map matching; matching a series of recorded geographic coordinates to a road network (Hsueh & Chen, 2018). All GPS points were featured on the network, after which route segments of the network corresponding to the location of the GPS points were manually selected to form a line, thus creating the observed route. Additionally, origin and destination points were generated from the GPS points; selecting the point with the first timestamp as Origin and the GPS point with the last timestamp as the Destination.

Developing of the alternative path model

The origin and destination points are necessary because they form the input for the alternative path model. An alternative path model provides different paths a bicyclist can take between their origin and destination point. The decision of a route is a discrete choice, since each turn offers two or more discrete alternatives; the other roads that lead to a destination. In transport research, discrete choice models offer two options: probit (probability unit) and logit (logistic regression) models. Cycling research predominantly uses logit models, since they are less computationally intensive and produce more accurate results than probit models (Menghini et al, 2010; Train, 2009; Ghareib, 1996).

There are different sorts of logit models. According to Menghini et al. (2010), the preferred model for cycling behaviour route choice analysis is the Multinomial Logit (MNL) model. This model consists of a finite number of choices that can be picked; the choice set. Moreover, alternatives are assumed to be independent, which is known as the Independent of Irrelevant Alternatives (IIA) property. This means that the model does not allow for unobserved correlation. Finally, each alternative is assigned its own utility value, based on which routes are chosen (McFadden, 1987). However, a MNL model contains a disadvantage. Routes that are similar or have a partial overlap are assumed to be uncorrelated, resulting in a different treatment of routes that are similar (Prato, 2009). Therefore, adapted logit models were created specifically to deal with overlapping routes.

On of these adapted logit models is the Mixed Logit model. This model deals with overlapping routes by allowing covariance between the error terms of the alternatives (Dane et al., 2019). It allows for coefficients to be randomly distributed, enabling understanding for heterogeneity among participants. This is important because linking heterogeneity to the characteristics of the research participants is preferable to a deterministic view of heterogeneity since the characteristics can be used for finding interaction effects (Hess, 2012). The drawback of the Mixed Logit is that probabilities for each route have to be approximated by solving algorithms; increasing computing time significantly (Train, 2009; p.139).

There are many route choice models ranging from different complicated Logit models with multiple route alternatives to a logistic regression analysis with just one route alternative. The advantages of more complicated models such as Mixed Logit are the ability to deal with overlapping routes whereas the drawbacks of complicated models are the computational intensity they require. According to Yáñez, Raveau and Ortúzar (2010), the conditional mixed logit model appears to be able to significantly explain the way alternative paths in a road network are perceived by travellers. Moreover, the conditional logit is able to deal with interaction effects and requires less computing time than other alternatives, which is feasible since the model has to be run on consumer grade hardware. Additionally, the mixed logit is an unstable approach with regard to results. Because the emphasis of this study is on the influence of the green environment, the greenest route is most important. Since the greenest route is generated based on different restrictions than the other labelled alternatives, the overlap between routes is assumed to be low. Therefore, this study uses a conditional logit choice model.

The conditional logit model starts with a conditional logit function (McFadden, 1975). The logit model is used to estimate individual-level coefficients. For the conditional logit model, the utility that individual i receives from alternative a, a = 1, 2, . . . , denoted by U_{ia}, is

$$U_{ia} = x_{ia}\beta_i + w_{ia}\alpha + z_i\delta_a + \varepsilon_{ia}$$

Where β_i are random coefficients that vary over individuals in the population, x_{ia} is a vector of alternative specific variables. α are fixed coefficients on w_{ia}, a vector of alternative-specific variables. δ_a are fixed alternative-specific coefficients on z_i; a vector of case-specific variables. ε_{ia} is the random error term that allows extreme value distribution (Hole, 2013). This formula is used during this research because it takes both personal characteristics and indicators of the built environment into account and applies it to a finite set of choices; the routes that form the choice set.

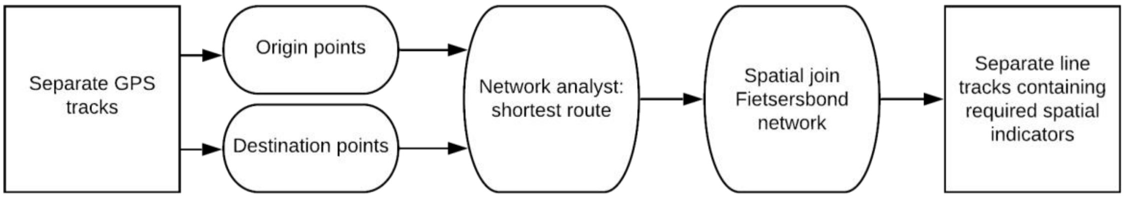
Generating alternative paths

The choice set is the set of all possible routes determined by the environment between an origin and a destination (Bovy and Stern 1990). Modelling all possible routes between an origin and destination requires much computing time depending on the number of options in the choice set, therefore the alternative path model consists of five labelled route alternatives: the shortest route, the greenest route, the traffic safest route, the socially safest route, and the fastest route.

The alternatives are generated so that segments collected from the participants are able to be compared to route alternatives generated based on origin and destination points retrieved from the GPS trackers. The 444 observed paths are compared to the five labelled alternatives. The labelled paths are defined as the optimal physical path with respect to a criterion function. The criteria in this case thus include short, fast, green, socially safe and traffic safe. The generation of the different labelled paths provides a choice set of alternative routes between origin and destination. It is important to compare different route alternatives because it is not correct to assume that every shortest path is also the worst path and every observed path the best, and that nature and scenic paths are chosen because of their green environment and not because they are in fact the shortest path. Nevertheless, the route alternatives provide the possibility to analyse whether indicators of the built environment influence route choice and whether any indicators occur more often than other ones in different alternatives.

Shortest paths
The observed paths are developed during the map matching process based on GPS tracking points that were retrieved from the GPS tracking devices. This process provided origin and destination points for each single route; routes with different origins and destinations. For the retour routes; routes with origin and destination in a similar PC6 area, 10 route points are generated so that the alternative routes can be generated based on points along the route rather than just the origin and destination. This OD-pair generation per route is necessary for the development of the alternative routes. The shortest route and the other alternatives are generated in a different manner. The development of the shortest route is visible in Figure 6.

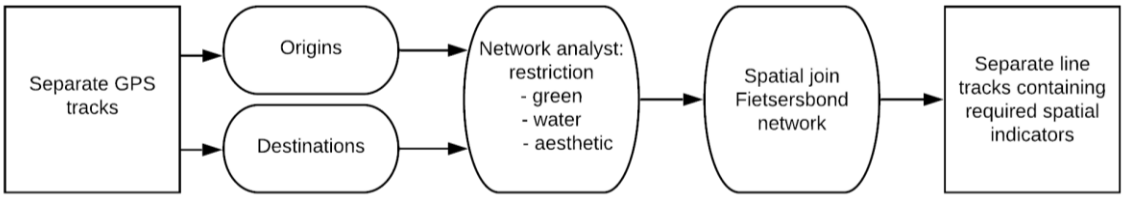
Figure 6 Development shortest routes



As shown in Figure 6, the shortest routes are generated along the Fietsersbond network based on the OD-points of each separate route track. The network analyst tool uses vector points and the lines that form the network to generate routes along the lines. These tracks are subsequently joined with the information stored in the Fietsersbond network via a spatial join, where segments that lie on the same location absorb information from the other route. This results in a line that represents the shortest route between the origin and destination of a cycled route, that contains attributes that describe the required spatial indicators. However, weather, daylight and bridges are not in the Fietsersbond network and thus not yet in the attribute line. Therefore, a python script, enclosed in Appendix G, adds these attributes to the lines; resulting in a shortest route line containing all required spatial indicators.

Green and other alternative paths
The development of the alternative routes differs from the development of the shortest route. The greenest route is taken as an example. It balances the need for a short distance with the requirement of routing along greenery, water, and an aesthetic landscape. Therefore, restrictions for each road in the network that value its traversability were added. This approach results in a line determining the route that takes into account both the environment with the variables green, water and aesthetic and the distance to be cycled. A simplified overview of the process is presented in Figure 7, whereas Appendix E provides an extensive explanation of the greenest route determination methodology.

Figure 7 Development greenest routes



As visible in Figure 7, restrictions are placed on each road in the network. These restrictions value a road segment according to the greenery in direct surroundings of the road, its proximity to water and the aesthetic value of the direct environment. The restrictions are not depicted as costs because costs create barriers, thereby preventing greenest route options that span 30 kilometres even though the observed route is but 3 kilometres because the environment is costly. In case the environment cost value is low, it signifies that the line is in a location on the network that is aesthetically pleasing, close to water and close to green according to the information in the network. Vice versa, if the cost of a restriction is high, the cell will be either far away from greenery and water and or not aesthetically pleasing. The four other route alternatives are generated similarly to the greenest route, just with other network restrictions. The network restrictions for the other alternatives are disclosed in Appendix G.

4.4.3 Spatial indicator preparation for statistical analysis

The spatial indicator preparation phase connects the indicators of the built environment with the route segments. Each generated line contains attributes that represent the spatial indicators. A python program selects the observed route and its alternative paths and depicts its spatial indicators as the example in Table 8. The code is enclosed in Appendix F.

Table 8 Example part of statistical analysis indicator preparation

Route	Alternative	water	bridges/km	aesthetic
T03_1_01	**Observed**	0.14	0.01	0.91
T03_1_01	**Green**	0.44	0.3	1.63
T03_1_01	**Shortest**	0	0	-0.45
T03_1_01	**Fastest**	0	0	-0.08
T03_1_01	**Traffic safe**	0.10	0	1.34
T03_1_01	**Social safe**	0	0	1

In this example, water is an indicator of the built environment. For this route, the valuation of water is that the observed route has 14% water per meter, where the green route would have 44% water per meter and the shortest route contains 0% water per meter and therefore does not encounter water at all. Bridges are points on the map. These points are counted and then divided by the length of the route, to account for difference in length per route. So, if a route crosses a bridge, the indicator bridges receives a positive value for the observed route. In this example, the shortest path does not cross a bridge, therefore indicator water is valued 0 for the shortest path. The aesthetic indicator value is approached similar to a Likert scale, where -2 is very displeasing and 2 is very pleasing, so in this example the greenest path would be most aesthetically pleasing and the shortest path the least. The valuation of all spatial indicators is enclosed in Appendix H. This provides a spatial overview of the route segments in relation to the green built environment.

Divergence from shortest route

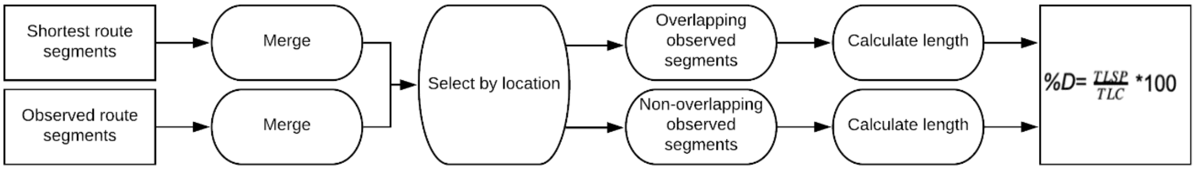
The observed paths and their alternatives provide the ability to analyse cyclists preference for environmental characteristics. The tracks in the database are divided into three categories in ArcGIS Pro using the 'select by location'. Segments that 'share a line segment' with the shortest path model are the shortest path category, whereas segments that do not are classified as the observed path category. In order to separate the observed paths and the shortest paths, an extra variable is added to the database. The variable is called path_identification. The value 0 distinguishes the track as the shortest path, whereas the value 1 discerns the track as the greenest path and 2 identifies the trace segments that are not on either the shortest or greenest path. This part of the research methodology identifies participants divergence from the shortest route with the following function:

Function 1 Calculate divergence from shortest route

$$\%D = \frac{\text{TSLP}}{\text{TLC}} * 100$$

Where %D is the percentage of divergence from the shortest route, TLC is the total length cycled and TLSP is the total length cycled on the shortest path. Figure 8 provides an overview of the methodology of this sub question.

Figure 8 Divergence from shortest route methodology



First, all shortest path segments and observed path segments are merged into one file discerning all routes that were taken in the categories. Thereafter, the lines are added to the map, resulting in an overlay of observed route segments that were cycled along the shortest paths and route segments that diverted from the shortest paths. Subsequently, the route segments that do not correspond with the shortest paths are exported to another file, after which the length of the total number of route segments that divert from the route is calculated. Another calculation provides the length of all shortest line segments, resulting in values that are required for function 1.

This function provides information on the route choices of the sample by determining what percentage of the total amount of cycling kilometres is not cycled on paths with the least amount of cost and the highest green- or scenic count.

Indicated and observed preference of cyclists

The indicated and observed preference of green environment features is analysed in a similar manner by comparing the overlapping segments in observed and green routes results with the opinions of participants that are retrieved from the survey. The indicated preference is measured by function 2:

Function 2 Calculate indicated preference for greenest route

$$\%IP = \frac{(\text{pos(WPFA)}/4)}{\text{p}} * 100$$

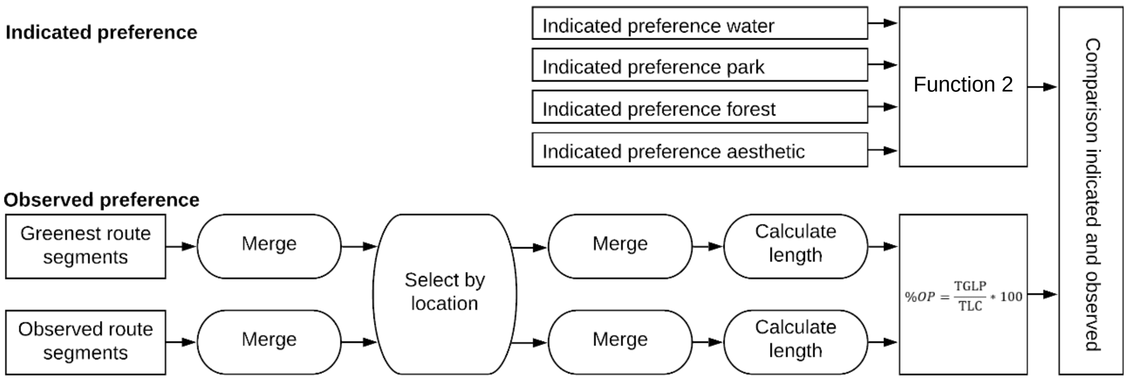
Where %IP is the percentage of indicated preference for the greenest route, (pos(WPFA))/4 is the mean of positive indications; agree and strongly agree on the Likert scale, with regard to the statements 9.1 (water), 9.2 (park), 9.3 (forest) and 9.4 (aesthetic) in the survey. These four statements are selected due to them being taken into account when creating the shortest route, as described in Figure 6. P is the total amount of participants that completed the survey. The observed preference is calculated by function 3:

Function 3 Calculate observed preference for greenest route

$$\%OP = \frac{\text{TGLP}}{\text{TLC}} * 100$$

Where %OP is the percentage of observed preference for the greenest route, TLC is the total length cycled and TLGP is the total length cycled on the greenest path. Figure 9 provides an overview of the methodology of the comparison between indicated and observed preference.

Figure 9 Preference for greenest route methodology

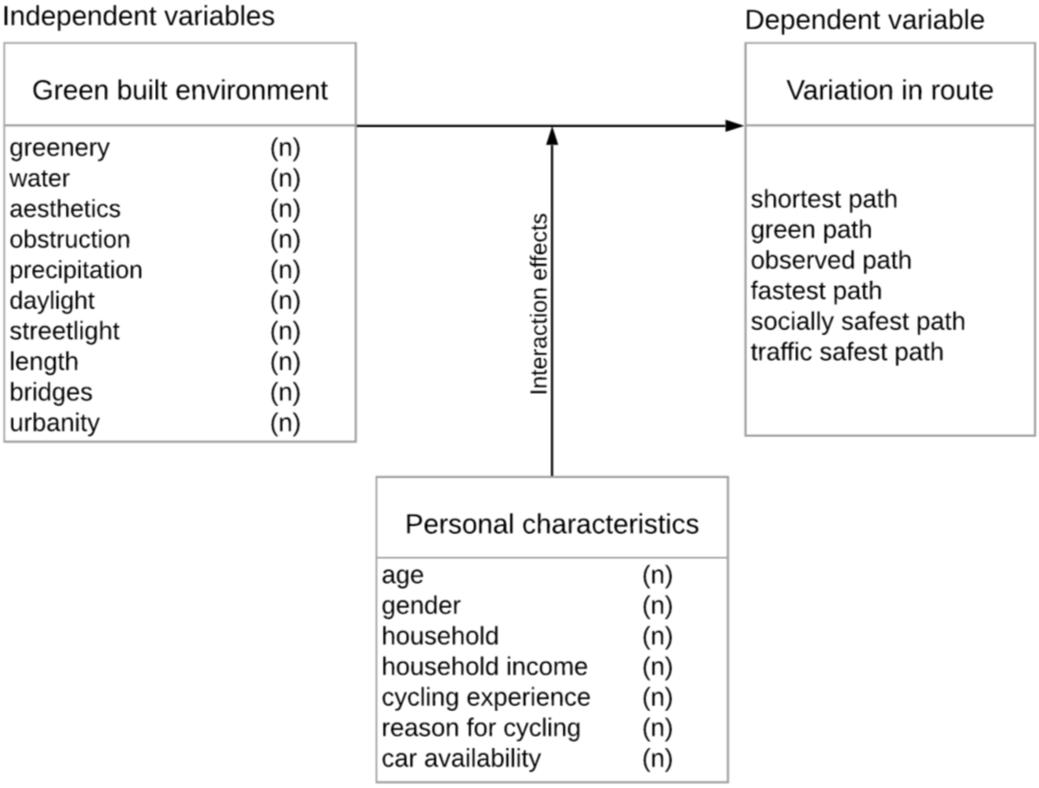


4.4.4 Statistical analysis

Choice model

The execution of the spatial indicator preparation delivers an output file that consists of the number of times the different labelled route options are allied with each of the indicators of the green built environment. Some of these variables are recalculated so that they are able to be taken into account in the statistical analysis. An explanation of the variables' values is enclosed in Appendix I. Based on this data, a conditional logit is created in the program STATA, resulting in an answer to how the indicators of the built environment influence route choice. The model models the path type, therefore the model predicts the reason why people choose a certain route. The model specification for the regression analysis is provided in Figure 10.

Figure 10 Relation between variables in conditional logit model



A conditional logit tests the influence of one or more independent variables (indicators of the green built environment and personal characteristics) on a dependent variable (variation in route). The result of the logit is a table with estimation results of variables that explain route choice. A distinction is made between main environment effects and interaction effects. This part of the research methodology determines which environment features are significant for route choice and the interaction effects of peoples' personal characteristics.

The conditional logit choice model is created based on the probabilities of choosing routes as a function of

- the green environment characteristics (variables *green_len, bridge_len, waterperc, obstruction, aesthetic, light, daylight, urbanity,* and *precipitation*)
- personal characteristics (variables sex, age, household, household income, cycling experience, car availability and trip purpose).

The characteristics are further elaborated upon in the variable description in the next section. In the data, there are observations for each route and each person. The variable choice is the dependent variable. It contains 0 or 1 depending on the chosen or the observed route. The set of the model determining the aggregation levels as person id and route id ensures that the fact that a person travels multiple routes is accounted for. The code that estimates the conditional logit model is enclosed in Appendix J.

Variable description

The variables that are modelled in this research are part of two categories: green environmental characteristics and personal characteristics. This section describes what these variables represent and the way in which they are constructed. Based on the preliminary research and the literature review, the first four variables; green_len, waterperc, aesthetic and bridge_len encompass the green environment. The other green environment characteristics are deemed important due to the literature review and the preliminary research, but do not make up the green environment. As for the personal characteristics, even though the preliminary research did not highlight a specific route preference for age and sex, the literature review did. The other personal characteristics are deemed influential based on the literature review. A comprehensive overview of the variables and their values is added in Appendix I.

Green environmental characteristics:

- *Green_len:* This variable is the premier variable within this category which quantifies the level of greenness of the environment along the route in a score that is normalized for the route length. Each street within the network is assigned to one of the categories from the Fietsersbond network in table E.1 in Appendix E. These categories are valued with the following factors, based on the preliminary research and the literature review:

Forest and nature	1
Meadows and trees	0.75
Built environment much green and rural	0.5
Built environment no green	0.1

  Green_len is then calculated is as follows: The number of segments in each route of each category is multiplied with their length. These categories are then multiplied with their corresponding factor, as specified as above. The sum of this value is taken for each route and divided by the route length.

$$\frac{\sum((segments * length) * factor)}{route\ length}$$

- *Waterperc:* Water percentage represents the percentage of a route which goes along the water. Both the literature review and the preliminary research have demonstrated that water is an important environmental characteristic. This value is calculated by taking the length of the route segments that pass a waterbody and dividing this by the total route length to calculate the percentage. The data on whether a route is in proximity to water is retrieved from the Fietsersbond network.

- *Aesthetic:* Aesthetic indicates the valuation of the environment surrounding the route. This is part of the category experience of the preliminary research. These valuations on the environments' aesthetic are retrieved from the Fietsersbond network. The value is calculated by taking the average of the Likert scale values of all the segments that make up the route.
- *Bridge_len:* This variable represents the number of bridges which have been encountered along the route. The reason that this variable is taken into account is because the preliminary research has shown that people experience bridges as an integral part of the green environment since they span water bodies and provide the ability to cycle above the water. This calculation of the variable consists of the number of bridges per route divided by the route length.
- *Obstruction:* This variable indicates the level of obstruction along the route. Obstruction along the route can be detrimental to the way people experience their environment. The value is calculated by taking the average of the Likert scale values of all the segments that make up the route. This data is retrieved from the Fietsersbond network.
- *Light:* This variable is an indication of the extent to which a route is lit by street lighting according to the categories in appendix I. Data on this is available in the Fietsersbond network. Literature has shown that a lack of street lighting may negatively affect the extent to which people take a green route.
- *Daylight:* The time of day during the trip is indicated by this variable. Both the literature review and the preliminary research have indicated that daylight is an important factor in the decision to cycle in a green environment. This value is based on the time of day at which the observed route took place.
- *Urbanity:* Urbanity represents whether the route goes through an urban or rural environment. This affects the green environmental characteristics, since meadows are an integral part of rural landscape whereas parks are part of the urban scenery and are not common in rural areas.
- *Precipitation:* Precipitation represents the state of the weather during the trip. This value is determined by the weather on the day at which the observed route took place.

Personal characteristics:

- *Sex:* This variable indicates the sex of the participant in a Boolean.
- *Age:* This variable indicates the age of the participant. It is calculated by subtracting the birth year from the participant from the current year; 2021.
- *Household:* Household showcases the composition of the household according to the categories in Table 9.
- *Household income:* Household income showcases the total income within the household according to the categories in Table 9.
- *Cycling experience:* This variable denotes the number of days a person cycles per week, ranging from daily to once per week.
- *Car availability:* This variable showcases whether and to which extent a household has access to a car.

Table 9 provides a descriptive of each variable along with their frequency for categorial variables and the summary statistics of the continuous variables. The table is classified according to the two categories green and personal characteristics, after which the tables are divided into continuous and categorical variables. The variable age is depicted separately and divided into categories to keep the table comprehensive, since the variable has many values.

The continuous environment variables are depicted both for all routes as well as just the observed routes, as the alternative routes can skew the overview, for example raising greenery because one of the alternatives is the greenest route. Likewise, the frequency for the categorical valuables seems very high. This is due to the fact that, in order to be able to analyse the characteristics, each alternative was valued similar to the characteristic in the observed route. For the observed values, values in the table must thus be divided by six. Therefore, the percentage of each frequency is added since the value is not dependent on the number of alternatives.

Table 9 Descriptives

Environment variables				
	mean	**st. dev.**	**min**	**max**
Continuous observed				
greenery	0.45	1.10	0	14.88
aesthetic	1.68	0.59	-1	2
streetlighting	0.13	0.19	0	3
water	16.49	73.49	0	1239.72
bridges	.00008989	.00094488	0	0.01
route length (km)	3.26	4.00	0	34.22
daylight	0.79	0.40	0	1
obstruction	0.45	0.26	0.7	3.44
Continuous all routes				
greenery	0.64	4.50	0	93.77
aesthetic	0.37	0.67	-1	3.44
streetlighting	1.62	0.98	0	3
water	15.68	58.14	0	1239.72
bridges	0.0002513	0.0015655	0	0.01
route length (km)	2.96	3.35	0	34.22
daylight	0.79	0.40	0	1
obstruction	1.33	0.76	0.7	4.07
	value		**value in Stata**	**frequency | %**
Categorical				
precipitation	no precipitation		0	1,392 | 52.13
	precipitation		1	1,278 | 47.87
urbanity	rural		0	1,212 | 45.39
	urban		1	1,458 | 54.61

Personal characteristics (1/2)			
	value	**value in Stata**	**frequency | %**
Categorical			
sex	female	0	1,962 | 73.48
	male	1	708 | 26.52
income	I do not know	.	
	less than € 2000	0	954 | 41.95
	between € 2000 and € 4000	1	990 | 43.54
	between € 4000 and € 6000	2	294 | 12.93
	more than € 6000	3	36 | 1.58
cycling experience	daily	0	1,680 | 62.92
	approximately 1 day per week	1	12 | 0.45
	approximately 2 days per week	2	120 | 4.49
	approximately 3 days per week	3	150 | 5.62
	approximately 4 days per week	4	162 | 6.07
	approximately 5 days per week	5	276 | 10.34
	approximately 6 days per week	6	270 | 10.11

Personal characteristics (2/2)			
	value	**value in Stata**	**frequency | %**
Categorical			
car availability	no	0	1,206 | 45.17
	yes, in consultation	1	654 | 24.49
	yes, always	2	810 | 30.34
household size	single without children living at home	0	210 | 7.87
	living together without children lah	1	66 | 2.47
	single with children living at home	2	696 | 26.07
	living together with children lah	3	426 | 15.96
	cohabiting with other adults	4	1,056 | 39.55
	living at home (lah)	5	216 | 8.09
trip purpose	leisure (sport, recreative)	een	507 | 21.35
	utilitarian functional (work/school, utilities)	een	
	utilitarian social (friends/family, other)	een	
	leisure + utilitarian functional	twee	228 | 8.54
	leisure + utilitarian social	twee	
	utilitarian functional + utilitarian social	twee	
	Leisure + utilitarian functional + utilitarian social	drie	1,872 | 70.11

Personal characteristics (3/3)							
Categorical							
Age	<20	20-29	30-39	40-49	50-59	60-69	>70
Frequency	90	1.554	210	78	336	354	48

Chapter 4 discussed the research methodology of this study. In short, the study encompasses conducting a revealed preference study into the influence of the green built environment on route choice of cyclists using GPS tracking and the collection of personal characteristics among cyclists through a survey. The results of performing the methodology are described in Chapter 5.

5

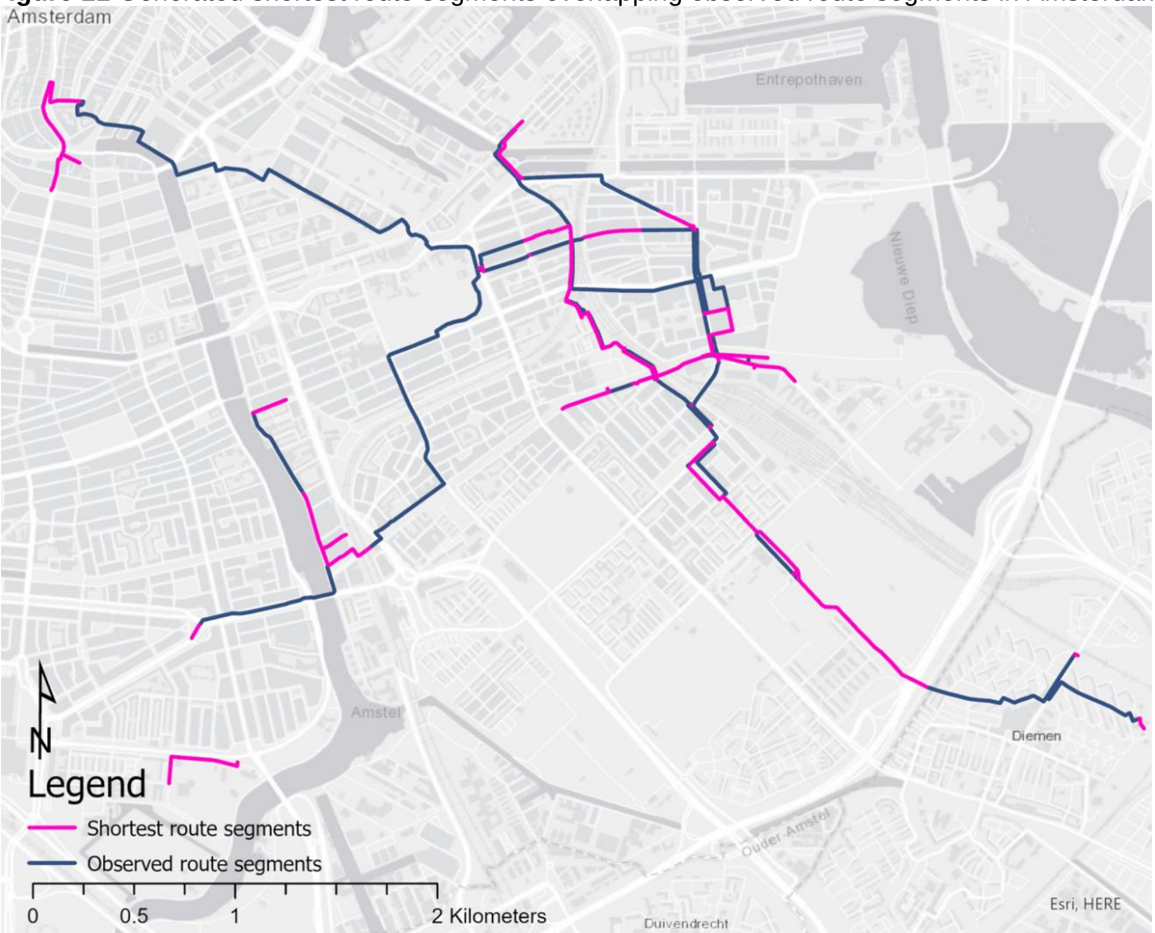
Results

Chapter 5 presents and discusses the results of the spatial analysis and the subsequent statistical analysis. The results of each sub question are presented; laying the foundation for the answer to the research question and either the acceptance or rejection of the research hypothesis; that based on this research samplel people are willing to divert from the shortest route to cycle through a green environment.

5.1 Divergence from the shortest route

This section investigates the extent to which people deviate from the shortest route. The preliminary study proved that people are willing to divert from the shortest route if it suits a purpose, cycling along a levee for example. Figure 11 depicts the observed and shortest route between origin and destination in Amsterdam, showing that in this city and in this study, participants do divert from the shortest route more often than not because very few of the observed blue route segments are coloured pink, which means that few routes were cycled on the generated shortest routes. The maps of other areas are enclosed in appendix K.

Figure 11 Generated shortest route segments overlapping observed route segments in Amsterdam



Source ESRI, HERE, adapted by author (2021)

The sample of Amsterdam is representative for the sample in the research area. The divergence function is valued according to the total number of cycled meters over the shortest route segments divided by the total number of observed cycled meters, presenting the following function:

$$\%D = \frac{296480.62 \ldots}{2377867.72..} = 12.46 \ldots$$

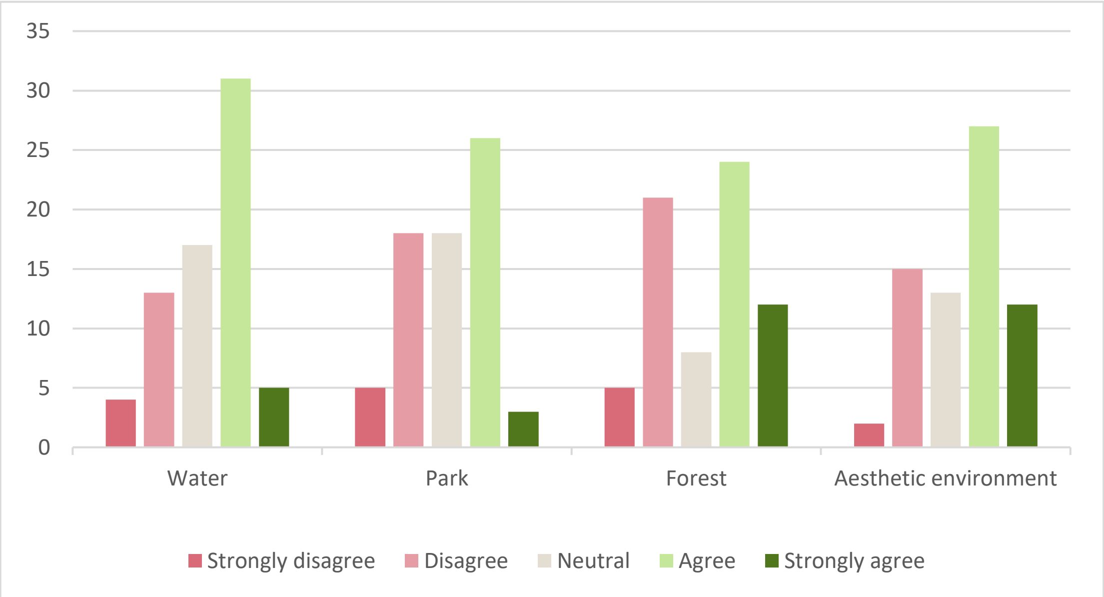
The extent to which people diverge from the shortest route is that 87.5% of the total distance cycled in this research has deviated from the shortest route. This is in contrast with the answer to the question whether people like to cycle the shortest route, where 70% of the participants answered confirming that they try to take the shortest route when cycling.

5.2 Indicated and observed preference of cyclists for the green environment

Indicated and observed preferences of cyclists can differ to a significant extent. This research measures the difference between indicated and observed preference by comparing the answers that participants provided on the survey for the indicated preference to the percentage of observed cycled meters on the greenest routes for the observed preferences.

Figure 12 indicates the participants' willingness to divert from the shortest route in order to cycle along the environment features water, park, forest and an environment that is aesthetically pleasing because it depicts the answers people provided on statements whether they would cycle an additonal disticance in order to encounter the environment feature. People are most willing to divert their route into an aesthetically pleasing environment, closely followed by cycling along water and through a park. Out of these four environment features, participants are least willing to divert from the shortest route for a forest.

Figure 12 Willingness to divert from the shortest route to cycle along an environment feature



Source Participant survey (2021)

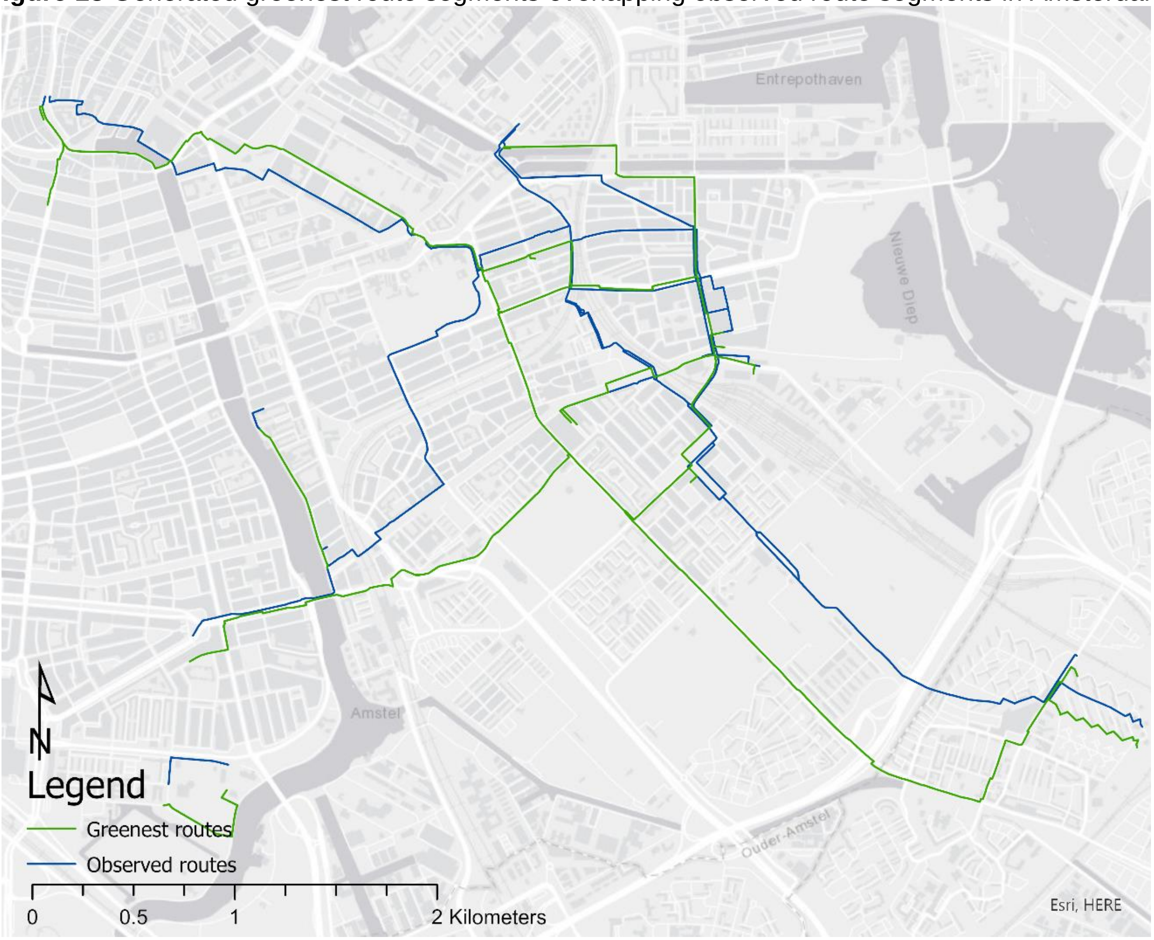
To calculate the percentage of indicated preference, the mean of the options 'agree' and 'strongly agree' is divided by the total amount of participants as described in the methodology. This provides the function

$$\%IP = \frac{(36 + 29 + 36 + 39)/4}{70} * 100 = 50$$

The function provides that 50% of the participants are willing to cycle a longer distance to cycle through a green environment. Based on this statement, it can be expected that the number of observed meters cycled on the greenest routes approaches 50%. However, Figure 12 and function 3 depict that this is not the case.

Figure 13 provides insight in the greenest route between origin and destination points of the GPS cycling trips in Amsterdam, showing that in this city and in this study, participants do not often cycle along the greenest route. The maps of other sub-areas in the research area are enclosed in appendix L.

Figure 13 Generated greenest route segments overlapping observed route segments in Amsterdam



Source ESRI, HERE, adapted by author (2021)

The sample of Amsterdam is representative for the sample in the research area. The observed preference function (3) is valued according to the total number of cycled meters over the greenest route segments divided by the total number of observed cycled meters, presenting the following function:

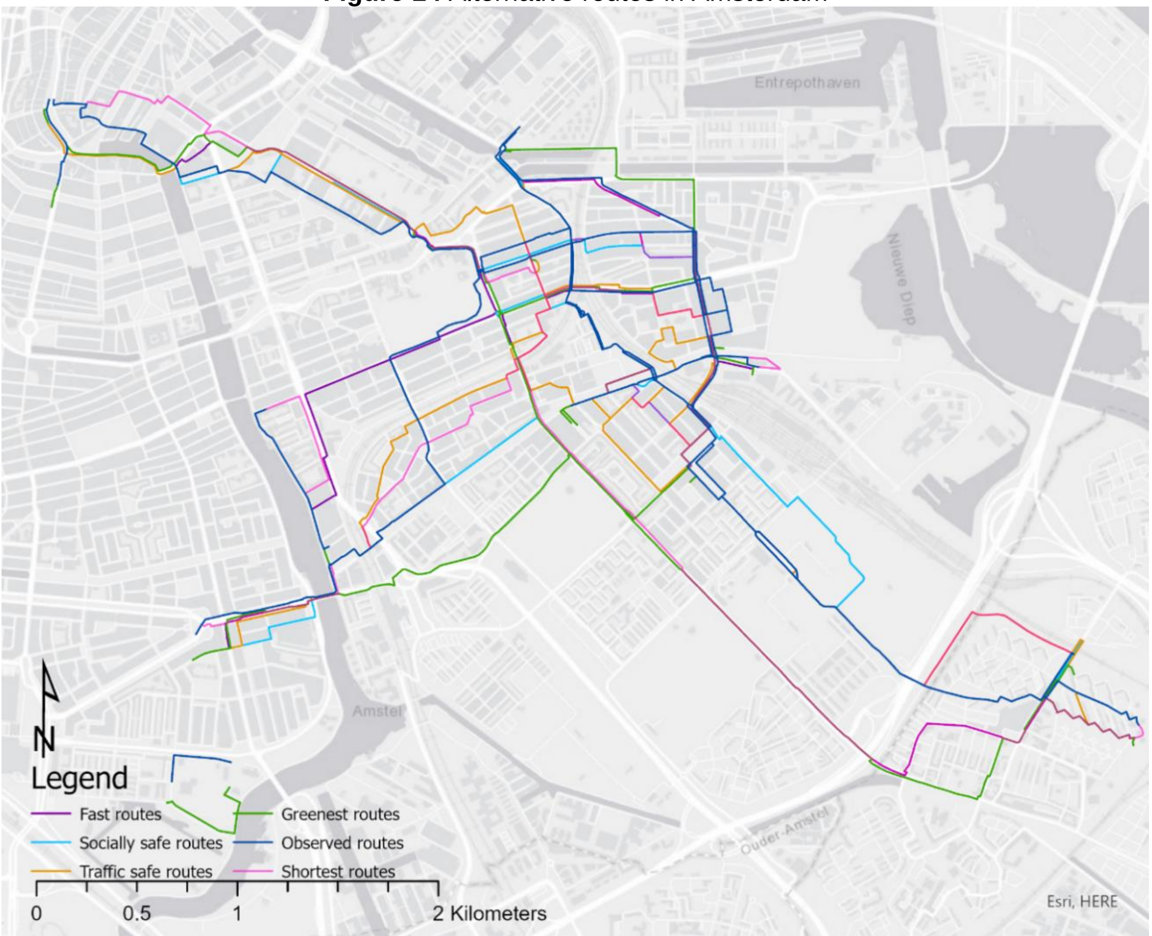
$$\%OP = \frac{163077.20 \ldots}{2377867.72 \ldots} = 6.85 \ldots$$

The difference between indicated and observed preference of cyclists for the green environment is thus 43.14%. This number is very high, implicating that people think they are willing to divert from the shortest route in order to cycle along attractive features of the built environment, but that they are not willing when faced with the reality and the impact of a longer route. Nevertheless, it is possible that people take another route that is also greener than the shortest route, but which does not match the generated greenest route. This may be due to the fact that people do not know which route is the greenest or that they are already satisfied if the taken route is slightly greener than the shortest possible route. Moreover, people can have other reasons to avoid greenest routes in reality. One of these reasons is expressed in the survey. In the additional comments, one participant writes "*As a young woman, my cycling route is substantially different during the day than my route in the evening / night / winter ... in the evening I avoid parks, for example. Also, in winter I do not ride next to the cold water, but I do in the summer".* This statement paves the way for section 5.4, in which the influence of personal characteristics on route choice are evaluated. Before that however, the influence of the green environment on route choice is described in section 5.3.

5.3 Influence of green environment characteristics on route choice

To analyse the influence of the green environment on route choice, five labelled route alternatives have been generated to form a choice set based on origin and destination points from observed routes. A visual rendition of a selection of the labelled routes is provided in Figure 14.

Figure 14 Alternative routes in Amsterdam



Source ESRI, HERE, adapted by author (2021)

The choice set thus consists of the observed route and five alternatives. Table 10 provides the result of estimating the effect of single green route choice characteristics on route choice with a significance of p<0.1. The abbreviation 'prob.' stands for probability.

Table 10 Effect of singular environment characteristics on route choice

Variable	Sign.	Effect
greenery	no	effect is not significant
aesthetic	yes	an attractive environment indicates increase of prob. of choosing route
water	no	effect is not significant
number of bridges	yes	increased presence of bridges indicates increase of prob. of choosing route
street lighting	yes	increased presence of streetlight indicates increase of prob. of choosing route
daylight	no within case variance	
precipitation	no within case variance	
obstruction	yes	decrease in obstruction indicates increase of prob. of choosing route
length (km)	yes	increase in length indicates increase of prob. of choosing route

In the singular effects of environmental variables on route choices, the amount of green and the number of water bodies close to a route were not significant, which means that no influence on cyclists route choice can be determined; whereas a decrease in obstruction, an increase in route length, more streetlight, and increasing attractiveness of the environment have a positive effect on route choice. Daylight and precipitation are unable to be modelled because there is not enough variance in the data. However, even though the fit of the singular environment models is better compared to the fit of no environment characteristic, a combination of different environmental characteristics provides a higher *log likelihood* and probability of obtaining the chi-square statistic given that there is in fact no effect of the independent variables on the dependent variable choice, and thus a better model fit compared to the singular environmental characteristics.

The combination of the characteristics fits best is a combination of the variables greenness, aesthetic, number of bridges, water proximity, route length and streetlighting. Table 11 provides the model.

Table 11 Bicycle route choice model green environment characteristics

Number of cases	=	444
Number of panels	=	59
Wald chi2(6)	=	62.36
Prob > chi2	=	0.0000
Std. Err. adjusted for 59 clusters in pid		

Characteristic	Odds Ratio	Robust Std. Err.	95% Conf. Interval	
greenery	0.45***	0.09	0.30	0.67
water	1.01***	0.002	1.00	1.02
aesthetic	34.03***	23.5	8.79	131.73
street lighting	0.01*	0.02	0.00	0.25

** = p<0.1, ** = p<0.05 and *** = p<0.01*

Based on this model, the variables greenery, aesthetic, water proximity and streetlighting are statistically significant. This means that an increase in greenery and increased presence of streetlight lowers the chance of a route being chosen, whereas an attractive environment and an increase in water along the route increases the chance of a route being chosen. This is not conform the research hypothesis, and thus unexpected. An explanation for the negative effect of streetlight could be that just 20% of the routes was cycled in darkness, thereby removing the necessity for streetlighting. The variables number of bridges and route length are not statistically significant, therefore no conclusions can be made based on their Odds Ratios.

When estimating the singular effect of route length, number of bridges and obstruction on route choice, all three variables are significant. Upon combining multiple variables however, they are not. This is due to the different variables influencing each other. Remarkable is that the mean of the length of observed routes is greater than the mean of the length of the greenest routes. This occurs due to the dataset consisting of both single and round trips, as detailed in section 6.2 in the discussion. In addition, an evaluation of the data provides that the generated green routes are shorter than the observed routes, which is in contrast with the study's hypothesis which assumes that people are willing to divert from the shortest route to cycle through a green environment. On top of that, the observed routes' sum of the variable aesthetic and water proximity is higher than the generated greenest sum of the variable, while the sum of the variable greenery for the observed is approximate to the sum of the generated green route. This is noteworthy because the alternative routes have been generated based on the research hypothesis. An explanation could be the difference in urbanity in the environment; the dataset consists of routes cycled in both rural and urban environments. Therefore, the dummy variable urbanity is created to test the hypothesis that the effect of the measure of greenery is different between urban and rural environments. The hypothesis is tested by measuring the interaction effect of the urbanity of the environment on the greenery of the chosen route.

The outcome of this model, as shown in Table 12, is that even though an increase in greenery is not significant; an increase in urbanity and greenery is and it increases the probability of a route being chosen with a factor of 1.36.

Table 12 Bicycle route choice model urbanity and greenery

Number of cases	=	444
Number of panels	=	59
Wald chi2(6)	=	5.76
Prob > chi2	=	0.0560
Std. Err. adjusted for 59 clusters in pid		

Characteristic	**Odds Ratio**	**Robust Std. Err.**	**95% Conf. Interval**	
greenery	0.95	0.04	0.87	1,03
greenery#urbanity	1.01*	0.18	1.05	1.76

** = p<0.1, ** = p<0.05 and *** = p<0.01*

Similar operations for the green environment variables water proximity and aesthetic indicate that an increase in urbanity and water along the route increases the probability of a route being chosen with a factor of 1.08 and an increase in urbanity and an increase in the environments' aesthetic increases the probability of a route being chosen with a factor of 9.69. This means that even though the influence of the greenery on route choice is negative overall; cyclists in urban areas do prefer a route with more water, greenery, and a pleasant environment, therefore the influence of the green environment on cyclists' route choice is demonstrated to be positive in urban areas.

In addition to the effect of the green environment on route choice, the preliminary research and theoretical framework indicate that street lighting pertains the choice for cycling through a green environment. Therefore, the effect of the variable light is tested for interaction with the variables of the green environment. The interaction effect of streetlight on greenery and aesthetic proves to be positive with a factor of 1.19 for greenery and a factor of 82.4 for aesthetic. In contrast, the presence of streetlight decreases the chance of a route in close proximity to water being chosen with a factor of 0.95.

This model estimation provides an overview of the influence of green environment characteristics have on bicyclists route choice in both rural and urban environments. It thus provides an overview of how green environment characteristics influence route choice of bicyclists. Section 5.4 will determine whether personal characteristics influence route choice.

5.4 Influence of personal characteristics on route choice

Based on the analysis in section 5.3, the combination of the urbanity of the environment; the greenness of a route, its proximity to water bodies and the aesthetic of the environment, contain a significant effect on cyclists' route choice. Even though the correlation matrix indicates that the personal characteristics do not correlate with the environment characteristics or the chosen route, Stata omits most personal characteristics from the dataset due to correlation errors upon combining personal characteristics. Therefore, an alternative approach of modelling the influence of personal characteristics on the influence of green environment on route chose has been executed. Interaction effects are determined based on the interaction of personal characteristics on the significant green environment variables; greenery, water proximity and aesthetic, because these are the significant variables that comprise the green environment. Each personal characteristic variable is tested against the effect of urbanity and the environment characteristic of route choice probability as well. The section concludes with an overview of the multiple mixed logit choice models.

5.4.1. Influence of personal characteristics on greenery on route on choice probability

The influence of personal characteristics in the case of greenery on route probability is significant just for age and household income. The characteristic age has a factor of 0.99; which means that a decrease in age indicates an increase in the probability of a route with much green being chosen. The characteristic household income is rated a factor of 0.14, which demonstrates that a decrease in income indicates a decrease in the probability of a green route being chosen with 86%.

5.4.2 Influence of personal characteristics on water availability on route choice probability

Contrary to the effect of personal characteristics on greenery on route choice probability, the influence of water availability on route choice probability is significant for all tested personal characteristics. The variable age receives a factor 0.99, which illustrates that a decrease in age indicates a decrease in the probability of a route passing water being chosen with 1%. The characteristics age and household income both receive a factor of 0.97, which implies that a being male leads to a decrease in the probability of a route passing water being chosen compared to being female and that a decrease in income indicates a decrease in the probability of a route passing water being chosen with 3%. The indicator trip purpose is valued with a factor 1.01 which demonstrates that an increase in the number of purposes people cycle for indicates a slight increase in the probability of a route passing water being chosen with 1%. Additionally, having access to a car leads to a 1% decrease in the probability of a route passing water being chosen compared to not having access to a car. The characteristic cycling experience demonstrates that an increase in cycling experience indicates a slight increase in the probability of a route passing water being chosen with 0.02%. Finally, the variable household is valued with a factor of 1.03, which implies that a decrease in the number of persons per household contains indicates an increase in the probability of route with proximity to water being chosen with 3%.

5.4.3 Influence of personal characteristics on aesthetic on route choice probability

For the environments' aesthetics' influence on the probability of a route being chosen, household size is the only significant personal characteristic. It is estimated at a factor of 1.32, which implies that a decrease in the number of persons a household contains indicates an increase in the probability of an urban aesthetically pleasing route being chosen.

Combining the influence of both environment and personal characteristics on route choice probability provides the overview in Table 13. If a cell has been left empty, this means the effect is not significant and therefore no conclusions can be made based on the value. The Table is created based on the single effects of one variable on another, therefore it is not a model. However, it is a comprehensive overview of factors influencing route choice based on the green environment.

Table 13 Bicycle route choice model singular significant characteristics

	route characteristic	personal characteristic	environment characteristic		
			greenery	*water*	*aesthetic*
effect of measure of environment characteristic on route choice probability					
	length/km		1.43***	1.001**	599.54***
interaction effects of urbanity and environment characteristic on route choice probability					
	length/km		1.36**	1.08***	9.96**
interaction effects of personal characteristics and environment characteristic on route choice probability					
		age	0.99**	0.99***	
		sex		0.97***	
		household income	0.14**	0.97***	
		household size		1.03***	1.32**
		cycling experience		1.002*	
		car availability		0.99*	
		trip purpose		1.01***	

** = p<0.01; ** = p<0.05 and *** = p<0.1*

Chapter 5 demonstrated the results of the study ordered by the four research sub questions. Chapter 6 will add to the results with a comparison of these results to previous research, provide an evaluation of the research process and present recommendations for future research.

6

Discussion

Chapter 6 will touch upon some of the issues encountered in the research process of this project and contains a reflection on the results presented in the previous chapter in section 6.1. In addition, covid-19 has impacted the data collection in this study. Section 6.2 will demonstrate its effect on the data sample, while section 6.3 will elaborate on the effect of covid-19 on the research process.

6.1 Research outcome compared to previous research

The result of the shortest route overlay demonstrates that people predominantly diverge from the shortest route, even though they indicate that they try to take the shortest route when prompted in the survey. It must be kept in mind that the generated shortest route might not be the shortest route according to the participants view, yet the general conclusion is that people do not choose the shortest route even though they say they will. This is in accordance with the result of both stated and revealed preference research, since stated preference studies demonstrate that people do not often divert from the shortest route (Mengheni et al., 2010; Broach et al., 2012), whereas the revealed preference study of Dill & Gliebe (2008; p.2) reveals that people do not often cycle the shortest route because cyclists combine their trip with other motives and purposes.

The greenest route overlay showcases that even though people state that they are willing to cycle longer to cycle through a green evironment, few people actually cycled the greenest route. It must be kept in mind that but one greenest route has been generated, and as such it is not ruled out that there are other routes with a similar measure of the green environment or that people do not necessarily want the most green; just some green. Another explanation could be retreived from Nello-Diakin and Harms (2019), who state that in a mature cycling context, a suitable environment for cycling is already provided and cyclists do not feel te need to limit themselves to green areas. Another possibility is raised by Skov-Peterson et al. (2018), who notice that green areas are sometimes avoided by cyclists because there is less street lighting and therefore feels unsafe. However, this is not directly applicable to the results of this research since the results provided a positive interaction effect between greenery and street light but a negative interaction effect between street light and water.

The analysis of the environment characteristics provided that in this research, there is a difference between the effect of green environmental variables on route choice based on the urbanity of an area. Participants in urban areas were more inclined to choose a route through a green environment than participants in rural areas. This is conform the conclusions of Vedel et al. (2017) and Hochmaier (2005), whose research areas were situated in an urban environment. Both studies demonstrate that people are willing to cycle further in order to pass greenery, both in the form of parks and other, and water. In contrast, Olde Kalter & Groenedijk (2018) state that in the Netherlands, a green environment influences cycling positively. Based on the result of this study, this statement is rejected. A possible explanation of the difference in preference based on urbanity, is that people in the countryside cycle less for greenery because they are more surrounded by nature than the people in the city. Even though meadows and forests are valued different in this study, it is possible that people interpret them as similarly green. Another component of the green environment is its aesthetic, since greenery and water are associated with a good aesthetic. In this study, aesthetic pertains a high positive influence on route choice behaviour, which confirms claims made by Lee and Moudon (2008), Wendel-vos et al. (2004) and Hochmair (2005) that an aesthetic environment influences route choice behaviour positively. Alternatively, the result of this study is contradictory with the findings of Bernardi et al. (2018) and with the findings of Kondo et al. (2009), who found no significant relation between aesthetic and the attractiveness of a cycling route. Bernardi et al. (2018) state that route choice in the Netherlands is not related to beauty as the majority of the study sample contains route with a high level of aesthetic and participants found it hard to detect a difference. It must be noted that the research of Bernardi et al. (2018) pertained a stated preference study, whereas this study is a revealed preference study. As earlier research demonstrated, differences between stated and revealed preference studies is to be expected.

To reduce complexity, the singular effect of personal characteristics and thefefore no overall model has been estimated. Based on these regressions, an increase in age lowers the chance of a route close to greenery and water being chosen. This outcome is contradictiory to statements made by Winters & Teschke (2010) and Mertens et al. (2014), who claim that age is not a significant predictor of route choice behaviour. In addition, it is inconsistent with Steer Davies Gleave (2012), who found that elderly possess a greater willingness to change their route for parks and green spaces. Nevertheless, the results in this study confirm research outcomes of Ma and Dill (2015), who state that younger people prefer a route with more green. In this study, it is found that being female increases the chance of a route with water being chosen. This is in accordance with findings of van Holle et al. (2014) and Vedel et al. (2017), who state that females are more willing to diverge from the shortest route in order to encounter green surroundings.

In contrast, cyclists from households with a low income in this research do not show a preference for cycling through a green enviroment, thereby confirming Stinson & Bhat (2003) who state that households with a low income are less sensitive to route preference. Moreover, this study demonstrates that an increase in household size leads to a higher preference for water along their cycling routes which is in contrast with findings from Tilahun et al. (2007) who state that households with less than two persons are more inclined to cycle a greener route.

The findings in this study are thus both confirming and contrasting earlier research. An important aspect is the difference between urban and rural areas, prompting the possibility for future research. Regardless, the outcome of a study is a reflection of its data. The upcoming section will present data limitations that have to be kept in mind when interpreting the results.

6.2 Data constraints and limitations

Each dataset contains its own limitations. In this section, the limitations of the research dataset will be discussed. This research has been carried out to the extent of the time, resources, and manpower available, which means that the research is as in-depth as allowed by the restrictions. Therefore, each data limitation is complemented with a suggestion for future research.

Due to covid-19 restrictions, the data in this study has been the result of tracking people who are known to the researchers. Even though differences in personal characteristics were kept in mind during the participant selection process, the familiarity of people impacts data quality as people are very enthusiastic and cycle differently than they would otherwise, even when they are explicitly asked not to. Furthermore, people have cycled with the GPS tracker for a week, thereby reducing the risk of having to meet an increasing amount of people during the lockdown. However, this results in multiple samples from the same participant; leading to overrepresentation of certain cycling motives since the trip frequency is different per participant. Even though the model accounts for this with panel data, the result of this research is thus not wholly representative for cyclists route choice. Future research could collect GPS data based on random sampling and single use tracking. A different option for the dataset could have been to use data from existing datasets. This approach was not taken because the creation of the new dataset allowed for the addition of personal characteristics, which is an addition to the existing pool of cyclists' route choice studies.

It should be noted that the GPS trackers which are crucial in this study are a data limitation in this study as well. Even though previous research suggests that GPS trackers are accurate within a range of 10 metres, random sampling throughout the GPS tracking process has indicated that the accuracy of the GPS trackers was lower. This proved to be problematic in the map matching process; due to the road network being dense in certain areas and GPS points varying in proximity to two parallel roads in the Fietsersbond Network, it was difficult for the software to trace which road segment was traversed. However, since the accuracy of a GPS is directly related to the built environment, the only option for future research is to develop more accurate GPS trackers or just tracking in areas with a low building height density.

Apart from the map matching, two data limitations are brought forth by the Fietsersbond Network shapefile. First, the shapefile is maintained by volunteers. This results in a shapefile in which the topology is not correct. Furthermore, the network is not up to date. There are instances of cycling paths not being recorded in the network, neither are shortcuts nor recently developed cycling paths. Since the Fietsersbond network is the basis for the generated routes, this sometimes results in generated routes that are less plausible. Observed routes are sometimes shorter than shorter route alternatives. Route 21_3_05 is a good example, where the distance of the shortest route was double the amount of the observed route due to three shortcuts missing from the network. An alternative explanation is that people can cycle over pavements and take illegal shortcuts, which are not able to be mapped correctly. In future research, another network could be used to prevent these shortcomings. Another explanation for the mean length of the observed routes being shorter than shortest routes is that many routes in the dataset are round trips, which means that they were cycled for leisure purposes. These routes were generated based on 10 points instead of just OD pairs as described in the methodology. However, the balance between cost of greenery and cost of distance is delicate for these routes since cyclists cycle for their pleasure and the network analyst tool is limited by its own possibilities.

The second limitation that stems from the Fietsersbond Network shapefile is that the attributes of the network are assembled by volunteers, thereby adding a subjective valuation to the network dataset. An example is the variable aesthetic; determined based on a Likert scale ranging from very aesthetically unpleasant to very aesthetically pleasant. Since each volunteer will have a different interpretation of aesthetic, the attributes are labelled subjectively. In future research, aesthetic could be rated through valuing environmental characteristics and calculating the mean of these environment characteristics to provide an objective environment aesthetic value. However, this course of action would require buffers, which leads to new data limitations. Since not all required spatial variables such as bridges are included in the Fietsersbond Network, these indicators have been added in the spatial data preparation phase based on the count of buffers around the spatial indicator that a route encounters. This approach lowers the accuracy of spatial data since the width of the buffers determines the count of the spatial variable. In addition, the difference in network density would have to be taken into account when determining buffer width, since urban networks are more dense than rural networks. Future research could consist of a sensitivity analysis on the width of the spatial indicator buffers to raise the accuracy of the spatial data.

The environments aesthetic is a good example of another data limitation. In this study, it is assumed that people who prefer a green route will primarily cycle along the greenest route. However, the generated greenest route is not the only route that passes water, greenery, or an aesthetic environment. Also, there are limitations to the fact that only one green route has been generated in combination with the possibly limited knowledge of the participants about the greenness of their environment. This is demonstrated in the dataset, in which the observed routes are often longer than the greenest routes. Since the hypothesis is that people are willing to diverge from the shortest route for a greener route, this either implies that people are willing to diverge from the shortest route further than expected, or that there is another factor influencing green route choice behaviour. A different option is that length as a cost has been valued too high, resulting in greenest routes that are too short compared to the possible greenness of the route. Future research could base the valuation of length as a cost as a function of the observed route; the shorter the route, the lower the cost of the length. Moreover, as explained earlier, the alternative routes are generated with the tool Network analyst, thereby limiting the alternatives to the abilities of the tool. This assumption could be tackled in future research by generating several greenest routes rather than just one greenest route and using different tools to generate alternatives with different cost valuations for length.

Another choice that requires explanation is the use of the conditional logit model rather than a model that deals with the assumption that alternatives are independent, which is known as the Independent of Irrelevant Alternatives (IIA) property. This means that the chosen choice model does not allow for unobserved correlation. However, this research is focused on the influence of the green environment, and therefore on the greenest route. Since the other alternatives are generated based on restrictions that are outside the scope of the green environment, overlap is assumed to be low. Moreover, the models have to be generated on consumer grade hardware, because the GIS laboratorial is not accessible due to covid-19 restrictions. The trade-off between the ability to deal with overlapping routes and the available time and resources led to the selection of the conditional logit. For future research, it is recommended to raise the available time and resources, after which a path size logit can be generated that does not violate the IIA property.

The data gathered in this study is remarkable because it contains data from both rural and urban environments compared to other data in cycling research which is predominantly based in urban environments. This fact is not necessarily a limitation, however it required the dummy variable urbanity to be able to generate conclusions from the data. Future research would benefit from a more extensive preliminary research consisting of more participants in both an urban and a rural environment rather than just the urban area of Zwolle. Nevertheless, the preliminary research was a valuable addition to the research because it provided a cyclists' perspective on indicators that were important for them when choosing their cycling route. By performing this research, a qualitative real-world component has been added to the dataset.

Nevertheless, the choice of the case and the method used is considered favourable taking into account the available time, resources, and manpower. It is recommended to gather data from more randomly sampled participants and not to use other research methods to avoid losing the overview and focus on the chosen methods. However, the case could be delineated in further research on the basis of a predetermined research area rather than the location of people willing to participate to avoid the necessity to add dummy variables such as urbanity to the dataset.

6.3 Covid-19 complications

Covid-19 has had a severe impact, both on the data collection process and the representativity of the collected data for route choice behaviour. The original data collection consisted of a randomly drawn sample of adresses in the Delft region, after which a letter would be sent to these adresses requesting volunteers to cycle with a GPS-tracker for a week. Due to the rising spread of the covid-19 virus, this sampling method was deemed irresponsible since it required volunteers to be visited in their homes, thus forcing more than the allowed three visitors per day. Therefore, a sample was created based on cycling patterns of friends and family. This caused just 20 GPS trackers being allocated to the research project rather than being able to track all participants in one week with 100 GPS trackers as envisioned. This led to a delay of three weeks.

The GPS tracking of participants was not the only drawback of the lockdown. Their cycling behaviour was altered as well. Even though the Dutch Kennis Instituut voor Mobiliteitsbeleid found that people cycle more during the covid-19 crisis (de Haas, Habersma & Faber, 2020), the survey demonstrates that particpants in this research cycled less due to the lockdown. The survey reveals that 61% of the respondents (partly) work from home during the lockdown, thereby removing trips to or from work from the dataset that would have existed in a world without covid restrictions. Covid-19 impacted cycling behaviour from respondents to the extent that just 21% of the respondents was not effected by the lockdown, with 4% cycling more and 66% cycling less to work or school. In constrast, cycling for leisure has increased for 43% of the participants, whereas 23% cycles less for leisure purposes. Another change to the dataset with regard to observed routes is that 25% of the respondents actively avoids busy cycling paths due to covid-19, thereby altering their route choice behaviour and thus making it harder to predict cycling behaviour through the route alternatives. The results of this study could therefore be explained by these new changes in behaviour, which complicates the comparison with related research due to the unique circumstances. Nevertheless, this thesis provides insight into cyclists' route choice behaviour during a nationwide lockdown.

Chapter 6 discussed this research outcome's meaning and interpretation while pondering the limitations of the gathered data and the research process. Chapter 7 will succeed the discussion with a conclusion that answers the sub questions and the main research question, thereby concluding the study.

7

Conclusion

In this thesis, the influence of the green environment on cyclists' route choice behaviour is studied. The main question is: *"How and to what extent does the green built environment influence bicyclists' route choice?"* The hypothesis for this thesis is that people choose to cycle along natural components such as greenery and proximity to water, even if they have to detour from the fastest route. To provide an answer to the main research question and to reject or confirm the hypothesis, five sub questions have been defined. These were divided into one qualitative research sub question and four quantitative research sub questions.

7.1 Sub questions

The qualitative sub question is "What are spatial indicators of the green built environment according to bicyclists in Zwolle?" Based on the preliminary research, six categories of spatial indicators of the built environment are important to bicyclists: experience, infrastructure, traffic and noise, aesthetics, green environments and water, and fast flow. These categories form the foundation for the spatial indicators required to answer the subsequent quantitative sub questions.

The first of these sub questions is: "To what extent do people diverge from the shortest route?" Based on the deference function, 88% of the total distance cycled in this research has deviated from the generated shortest route. This outcome is conforming earlier research, in which cyclists predominantly avoid the shortest route to combine trip purposes (Dill & Gliebe, 2008; p. 2).

The second sub question is: "To what extent is there a difference between indicated and observed preference for the green environment of cyclists?" The difference between the indicated and observed preference is 43%. Even though the survey indicated that people are willing to cycle further to encounter greenery, water and good aesthetics on their routes, the reality was that the greenest route was cycled only 7% of the total length cycled in this study. However, this could be due to the fact that just one greenest route was generated in this research.

The third sub question is: "How do green environment characteristics influence route choice of bicyclists?" The green environment characteristics that encompass the green environment are number of bridges, greenery, water and aesthetic. In this study, the number of bridges does not influence route choice. Alternatively, for the whole research area, an increase of greenery decreases the chance of a route being chosen while proximity to water and an aesthetically pleasing environment increase the chance of a route being chosen. In contrast, in urban environments all three factors separately influence route choice positively, thus increasing the chance of a route being chosen.

The fourth sub question is: "How do personal characteristics influence route choice of bicyclists?" In this study, there is no final conclusion to how a combination of personal characteristics influences route choice of cyclists since no fitting model was estimated. However, a higher age and income implicates a lower chance of a green route being chosen. Alternatively, a lower age, being male, having a relatively lower income and not having a car available decreases the chance of a route that encounters water being chosen. In contrast, more cycling experience, an increase in household size and an increase in the number of trip purposes indicates a higher change of a route that passes water being chosen. The personal characteristic household influences the chance of an appealing route being chosen as well, pertaining a bigger household with the higher chance than a smaller household.

7.2 Main Research Question

In conclusion, the green environment does influence cyclists' route choice. Since the estimation of a model that adds personal characteristics to the environmental characteristics is an opportunity for future research, the research question is answered based on the characteristics of the green environment. As such, the conclusion of this research is that the answer to the research question differs between urban and rural areas. Overall, greenery along a route decreases the chance of a route being chosen with a factor of 0.44, whereas the presence of water slightly increases the chance of a route being chosen with a factor of 1.01. Looking at the effect of a variable on route choice, the determining factor in this research is the aesthetic of the environment with a factor of 34.0. Conversely, an increase in urbanity as well as the presence of the three environment characteristics increases the chance of a route being chosen. Based on the findings in this research, the research hypothesis stating that people are willing to divert from the shortest route to cycle through a green environment is thus accepted for cyclists in cycling in urban areas. Cyclists in general do appear willing to cycle further for water and an appealing environment but not for more green along the way. The hypothesis is therefore overall neither confirmed nor rejected.

The implication of this research for the Dutch government goal of promoting bicycling is thus that in order to promote cycling; planning cycling paths in proximity to greenery, water and an appealing environment will increase the probability of a route being chosen in an urban context. Overall, water and an aesthetic environment will increase the chance of a route being chosen.

7.3 Future research

The conclusion of this study answers the questions that were defined in the introduction, but it raises questions as well. One of these questions is the exact influence of urbanity on route choice behaviour. This study proved that a higher urbanity increases the odds of a green route being chosen. However, the difference in urbanity could be influential in more areas of the build environment, prompting opportunities for further research. Another question raised from this study is the influence of daylight on the influence of streetlight on route choice with regard to the green environment. This dataset primarily contained routes cycled during the day because of the fact that there is less reason to cycle in the evening due to everything being closed on account of covid-19 restrictions. This means that the negative influence of street lighting on route choice that was found is not representative outside of the context of the lockdown. Therefore, it is recommended to further investigate the difference in route choice behaviour in settings with different urbanity and in a time without covid-19 restrictions.

Moreover, the study can be re-performed in different ways. The first concerns the data sample, creating a different sample that consists of randomly drawn participants. One option could be randomly selecting addresses from the Key register of Buildings and Addresses in one urban and one rural research area, sending letters requesting participation rather than using convenience sampling. Other possibilities to deepen the research are a longer observation time with more participants with additional indicators regarding weather and daylight, developing new ways to isolate cycling trips from all other trips with similar speeds such as rollerblading and running, generating multiple green routes and estimating a path size logit rather than a conditional logit to deal with overlap between routes.

In conclusion, while it is not proven that everybody in the Netherlands cycles, as claimed at the introduction of this research; those that do mostly prefer to cycle through a green environment and others choose to encounter water and a beautiful scenery.

8

References

Adekoya, A. A., & Guse, L. (2020). Walking Interviews and Wandering Behavior: Ethical Insights and Methodological Outcomes While Exploring the Perspectives of Older Adults Living With Dementia. *International Journal of Qualitative Methods*, *19*.

Aldred, R., & Dales, J. (2017). Diversifying and normalising cycling in London, UK: An exploratory study on the influence of infrastructure. *Journal of Transport & Health*, *4*, 348-362.

Allan, A. (2016, November). EBike Performance in Urban Commuting. How does it compare to Motorised Modes?. In *Australasian Transport Research Forum (ATRF), 38th, 2016, Melbourne, Victoria, Australia*.

Antonakos, C. L. (1994). Environmental and travel preferences of cyclists.

Aultman-Hall, L. M. (1996). *Commuter bicycle route choice: analysis of major determinants and safety implications* (Doctoral dissertation).

Aziz, H. A., Nagle, N. N., Morton, A. M., Hilliard, M. R., White, D. A., & Stewart, R. N. (2018). Exploring the impact of walk–bike infrastructure, safety perception, and built-environment on active transportation mode choice: a random parameter model using New York City commuter data. *Transportation*, *45*(5), 1207-1229.

Barton, J., & Pretty, J. (2010). What is the best dose of nature and green exercise for improving mental health? A multi-study analysis. *Environmental science & technology*, *44*(10), 3947-3955.

Ben-Akiva M.E., Ramming M.S., Bekhor S. (2004) Route Choice Models. In: Schreckenberg M., Selten R. (eds) Human Behaviour and Traffic Networks. Springer, Berlin, Heidelberg.

Bernardi, S., La Paix Puello, L., & Geurs, K. (2018). Modelling route choice of Dutch cyclists using smartphone data. *Journal of transport and land use*, *11*(1), 883-900.

Bhat, C.R. (2003) “Random Utility-Based Discrete Choice Models for Travel Demand analysis”, In: K.G. Goulias (ed.) Transportation systems planning, pp.(10)1-(10)29. CRC Press: Washington, D.C.

Blatt, A. J. (2015). Data privacy and ethical uses of Volunteered Geographic Information. In *Health, Science, and Place* (pp. 49-59). Springer, Cham.

Bohte, W., & Maat, K. (2009). Deriving and validating trip purposes and travel modes for multi-day GPS-based travel surveys: A large-scale application in the Netherlands. *Transportation Research Part C: Emerging Technologies*, *17*(3), 285-297.

Bonham, J., & Koth, B. (2010). Universities and the cycling culture. *Transportation research part D: transport and environment*, *15*(2), 94-102.

Brick, E., McCarthy, O., & Caulfield, B. (2012). Bicycle Infrastructure Preferences – A case study of Dublin (p. 18). Transportation Research Board 91st meeting. Washington, DC.

Broach, J., Dill, J., & Gliebe, J. (2012). Where do cyclists ride? A route choice model developed with revealed preference GPS data. *Transportation Research Part A: Policy and Practice*, *46*(10), 1730-1740.

Bryman, A. (2012) Social Research Methods. Oxford: Oxford University Press.

Cao, X., Mokhtarian, P. L., & Handy, S. L. (2009). Examining the impacts of residential self-selection on travel behaviour: a focus on empirical findings. *Transport reviews*, *29*(3), 359-395.

Casello, J. M., & Usyukov, V. (2014). Modeling cyclists’ route choice based on GPS data. *Transportation Research Record*, *2430*(1), 155-161.

Cervero, R., & Kockelman, K. (1997). Travel demand and the 3Ds: Density, diversity, and design. *Transportation research. Part D, Transport and environment*, *2*(3), 199-219.

Chen, P., Shen, Q., & Childress, S. (2018). A GPS data-based analysis of built environment influences on bicyclist route preferences. *International journal of sustainable transportation*, *12*(3), 218-231.

Copenhagen IZE index (2019) *The most bicycle friendly cities of 2019.* Retrieved from https://copenhagenizeindex.eu/ on 08.09.2020.

Dane, G., Feng, T., Luub, F., & Arentze, T. (2019). Route choice decisions of E-bike users: Analysis of GPS tracking data in the Netherlands. In *The Annual International Conference on Geographic Information Science* (pp. 109-124). Springer, Cham.

De Geus, B., De Bourdeaudhuij, I., Jannes, C., & Meeusen, R. (2008). Psychosocial and environmental factors associated with cycling for transport among a working population. *Health education research*, *23*(4), 697-708.

Depledge, M. H., Stone, R. J., & Bird, W. J. (2011). Can natural and virtual environments be used to promote improved human health and wellbeing?.

Dessing, D., de Vries, S. I., Hegeman, G., Verhagen, E., Van Mechelen, W., & Pierik, F. H. (2016). Children's route choice during active transportation to school: difference between shortest and actual route. *International journal of behavioral nutrition and physical activity*, *13*(1), 48.
De Haas, M., Habersma, M. & Faber, R. (2020). *Mobiliteit in de coronacrisis: effecten van de coronacrisis op mobiliteit en mobiliteitsbeleving.* Den Haag: Kennisinstituut voor Mobiliteitsbeleid.
De Vries, M. (2020) De nieuwste cijfers*. De Volkskrant Zaterdagbijlage 24 oktober 2020*, p. 3.
Dill, J., & Gliebe, J. (2008). Understanding and measuring bicycling behavior: A focus on travel time and route choice.
Eenink, R. (2018) Cycling in Amsterdam, if you can do it here, you'll do it anywhere. In: Tira, M., & Pezzagno, M. (2018). Town and Infrastructure Planning for Safety and Urban Quality: Proceedings of the XXIII International Conference on Living and Walking in Cities (LWC 2017), Brescia, Italy, 15–16 June 2017.
Etikan, I., Musa, S. A., & Alkassim, R. S. (2016). Comparison of convenience sampling and purposive sampling. *American journal of theoretical and applied statistics*, *5*(1), 1-4.
Evans, J., & Jones, P. (2011). The walking interview: Methodology, mobility and place. *Applied Geography*, 31(2), 849–858.
Ewing, R., & Cervero, R. (2010). Travel and the built environment: a meta-analysis. *Journal of the American planning association*, *76*(3), 265-294.
Ewing, R., Tian, G., Lyons, T., & Terzano, K. (2017). Trip and parking generation at transit-oriented developments: Five US case studies. *Landscape and Urban Planning*, *160*, 69-78.
Feddes, F., de Lange, M., & Brömmelstroet, M. (2020). Hard work in paradise. The contested making of Amsterdam as a cycling city. *The Politics of Cycling Infrastructure: Spaces and (In) Equality*, 133.
Fietsberaad (2020) *Tour de Force*. Retrieved from https://www.fietsberaad.nl/tour-de-force/home on 08.09.2020.
Fietsersbond (2013) *Hoeveel kilometer fietspad is er in Nederland?* Retrieved from https://www.fietsersbond.nl/nieuws/bijna-35-000-km-fietspad-in-nederland/ on 16.11.20.
Fietsfilevrij (2020) *Rotterdam-Delft*. Retrieved from http://www.fietsfilevrij.nl/fietsroutes/rotterdam-delft/ on 22.09.2020.
Fishman, E., Böcker, L., & Helbich, M. (2015). Adult active transport in the Netherlands: an analysis of its contribution to physical activity requirements. *PloS one*, *10*(4), e0121871.
Foster, C. E., Panter, J. R., & Wareham, N. J. (2011). Assessing the impact of road traffic on cycling for leisure and cycling to work. *International journal of behavioral nutrition and physical activity*, *8*(1), 61.
Frejinger, E., & Bierlaire, M. (2007). Capturing correlation with subnetworks in route choice models. *Transportation Research Part B: Methodological*, *41*(3), 363-378.
Fu, L., & Farber, S. (2017). Bicycling frequency: A study of preferences and travel behavior in Salt Lake City, Utah. *Transportation research part A: policy and practice*, *101*, 30-50.
Gardner, G. (1998). Transport implications of leisure cycling. Berkshire: Transport Research Laboratory.
Ghanayim, M., & Bekhor, S. (2018). Modelling bicycle route choice using data from a GPS-assisted household survey. *European Journal of Transport and Infrastructure Research*, *18*(2).
Ghareib, A. H. (1996). Evaluation of logit and probit models in mode-choice situation. *Journal of transportation engineering*, *122*(4), 282-290.
Gössling, S., Humpe, A., Litman, T., & Metzler, D. (2019). Effects of perceived traffic risks, noise, and exhaust smells on bicyclist behaviour: An economic evaluation. *Sustainability*, *11*(2), 408.
Harms L (2006) Anders onderweg. De mobiliteit van allochtonen en autochtonen vergeleken. The Hague: Social and Cultural Planning Office.
Heesch, K. C., Sahlqvist, S., & Garrard, J. (2012). Gender differences in recreational and transport cycling: A cross-sectional mixed-methods comparison of cycling patterns, motivators, and constraints. *International Journal of Behavioral Nutrition and Physical Activity*, 9, 106.
Heinen, E., Maat, K., & Van Wee, B. (2011). The role of attitudes toward characteristics of bicycle commuting on the choice to cycle to work over various distances. *Transportation research part D: transport and environment*, *16*(2), 102-109.
Hess, S. (2012). Rethinking heterogeneity: the role of attitudes, decision rules and information processing strategies. *Transportation Letters*, *4*(2), 105-113.
Hochmair, H. (2005). Towards a classification of route selection criteria for route planning tools. In *Developments in Spatial Data Handling* (pp. 481-492). Springer, Berlin, Heidelberg.
Hood, J., Sall, E., & Charlton, B. (2011). A GPS-based bicycle route choice model for San Francisco, California. *Transportation letters*, *3*(1), 63-75.

Hole, A. R. (2013) Mixed logit modelling in STATA. Retrieved from https://www.Stata.com/meeting/uk13/abstracts/materials/uk13_hole.pdf on 13.02.21.
Holligan, A. (2013). Why Is Cycling so Popular in the Netherlands?. *News. BBC News Magazine*.
Hopkinson, P., & Wardman, M. (1996). Evaluating the demand for new cycle facilities. *Transport Policy*, *3*(4), 241-249.
Howard, C., & Burns, E. K. (2001). Cycling to work in Phoenix: Route choice, travel behavior, and commuter characteristics. *Transportation Research Record*, *1773*(1), 39-46.
Huss, A., Beekhuizen, J., Kromhout, H., & Vermeulen, R. (2014). Using GPS-derived speed patterns for recognition of transport modes in adults. *International journal of health geographics*, *13*(1), 40.
Hull, A., & O'Holleran, C. (2014). Bicycle infrastructure: can good design encourage cycling?. *Urban, Planning and Transport Research*, *2*(1), 369-406.
Hsueh, Y. L., & Chen, H. C. (2018). Map matching for low-sampling-rate GPS trajectories by exploring real-time moving directions. *Information Sciences*, *433*, 55-69.
Johansson, C., Lövenheim, B., Schantz, P., Wahlgren, L., Almström, P., Markstedt, A., ... & Sommar, J. N. (2017). Impacts on air pollution and health by changing commuting from car to bicycle. Science of the total environment, 584, 55-63.
Karanikola, P., Panagopoulos, T., Tampakis, S., & Tsantopoulos, G. (2018). Cycling as a smart and green mode of transport in small touristic cities. *Sustainability*, *10*(1), 268.
Kim, S., Mankoff, J., & Paulos, E. (2013, February). Sensr: evaluating a flexible framework for authoring mobile data-collection tools for citizen science. In *Proceedings of the 2013 conference on Computer supported cooperative work* (pp. 1453-1462).
Kondo, K., Lee, J. S., Kawakubo, K., Kataoka, Y., Asami, Y., Mori, K., ... & Akabayashi, A. (2009). Association between daily physical activity and neighborhood environments. *Environmental Health and Preventive Medicine*, *14*(3), 196-206.
Krenn, P. J., Oja, P., & Titze, S. (2014). Route choices of transport bicyclists: a comparison of actually used and shortest routes. *International journal of behavioral nutrition and physical activity*, *11*(1), 31.
Kroes, E. P., & Sheldon, R. J. (1988). Stated preference methods: an introduction. *Journal of transport economics and policy*, 11-25.
Kusenbach, M. (2003). Street phenomenology: The go-along as ethnographic research tool. *Ethnography*, *4*(3), 455-485.
Lee, C., & Moudon, A. V. (2008). Neighbourhood design and physical activity. *Building research & information*, *36*(5), 395-411.
Lin, J. J., Zhao, P., Takada, K., Li, S., Yai, T., & Chen, C. H. (2018). Built environment and public bike usage for metro access: A comparison of neighborhoods in Beijing, Taipei, and Tokyo *Transportation Research Part D: Transport and Environment*, *63*, 209-221.
Lu, W., Scott, D. M., & Dalumpines, R. (2018). Understanding bike share cyclist route choice using GPS data: Comparing dominant routes and shortest paths. *Journal of transport geography*, *71*, 172-181.
Luther, K., Counts, S., Stecher, K. B., Hoff, A., & Johns, P. (2009). Pathfinder: an online collaboration environment for citizen scientists. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 239-248).
McFadden, D. (1977). *Quantitative methods for analyzing travel behavior of individuals: some recent developments*. Berkeley: Institute of Transportation Studies, University of California.
McFadden, D. (1987). Regression-based specification tests for the multinomial logit model. *Journal of econometrics*, *34*(1-2), 63-82.
Menghini, G., Carrasco, N., Schüssler, N., & Axhausen, K. W. (2010). Route choice of cyclists in Zurich. *Transportation research part A: policy and practice*, *44*(9), 754-765.
Mertens, L., Van Dyck, D., Ghekiere, A., De Bourdeaudhuij, I., Deforche, B., Van de Weghe, N., & Van Cauwenberg, J. (2016). Which environmental factors most strongly influence a street's appeal for bicycle transport among adults? A conjoint study using manipulated photographs. *International journal of health geographics*, *15*(1), 1-14.
Misra, A., & Watkins, K. (2018). Modeling cyclist route choice using revealed preference data: an age and gender perspective. *Transportation Research Record*, *2672*(3), 145-154.
Mokhtarian, P. L., & Cao, X. (2008). Examining the impacts of residential self-selection on travel behavior: A focus on methodologies. *Transportation Research Part B: Methodological*, *42*(3), 204-228.
Mooney, P., Olteanu-Raimond, A. M., Touya, G., Juul, N., Alvanides, S., & Kerle, N. (2017). Considerations of privacy, ethics and legal issues in volunteered geographic information.

Moudon, A. V., Lee, C., Cheadle, A. D., Collier, C. W., Johnson, D., Schmid, T. L., & Weather, R. D. (2005). Cycling and the built environment, a US perspective. *Transportation Research Part D: Transport and Environment*, *10*(3), 245-261.
Nawrath, M., Kowarik, I., & Fischer, L. K. (2019). The influence of green streets on cycling behavior in European cities. *Landscape and urban planning*, *190*, 103598.
Nello-Deakin, S., & Harms, L. (2019). Assessing the relationship between neighbourhood characteristics and cycling: Findings from Amsterdam. *Transportation research procedia*, *41*, 17-36.
Ngosong, T.F. (2015) The built environment discipline and its research at doctoral level. *School of the Built Environment, College of Science and Technology, University of Salford Manchester*.
Ogra, A., & Ndebele, R. (2014). The role of 6Ds: Density, diversity, design, destination, distance, and demand management in transit oriented development (TOD).
Olde Kalter, M. J. & Groenendijk, L. (2018). Aantrekkelijkheid en afwisseling routes meer sturend in keuzegedrag fietsers dan snelheid.
Ouis, D. (2001). Annoyance from road traffic noise: a review. *Journal of environmental psychology*, *21*(1), 101-120.
Ortuzar, J., Iacobelli, A., & Valeze, C. (2000). Estimating demand for a cycle-way network. *Transportation Research Part A: Policy and Practice*, *34*(5), 353-373.
Parkin, J., Wardman, M., & Page, M. (2007). Models of perceived cycling risk and route acceptability. *Accident Analysis & Prevention*, *39*(2), 364-371.
Pelzer P (2010) Fietsmulticulturalisme. Agora 26: 17–20.
Poenaru, S., Rouhani, S., Poggi, D., Moch, A., & Colas, C. (1987). Study of the pathophysiological effects on chronic exposure to environmental noise in man. *Acoustics letters*, *11*(5), 80-87.
Prato, C. G. (2009). Route choice modeling: past, present and future research directions. *Journal of choice modelling*, *2*(1), 65-100.
Pritchard, R. (2018). Revealed preference methods for studying bicycle route choice - A systematic review. *International journal of environmental research and public health*, *15*(3), 470.
Roof, K., & Oleru, N. (2008). Public health: Seattle and King County's push for the built environment. *Journal of environmental health*, 71(1), 24-27.
Sangiambut, S., & Sieber, R. (2016). The V in VGI: Citizens or civic data sources. *Urban Planning*, *1* (2), 141-154.
Sarjala, S. (2019). Built environment determinants of pedestrians' and bicyclists' route choices on commute trips: Applying a new grid-based method for measuring the built environment along the route. *Journal of transport geography*, *78*, 56-69.
Selby, B., Copperman, R., DeBoer, K., Brown, E., Komanduri, A., Livshits, V., & Kuppam, A. (2018). *Use of Convenience Sampling: Benefits and Challenges from the Phoenix, Arizona, Area Household Travel Survey* (No. 18-04913).
Sener, I. N., Eluru, N., & Bhat, C. R. (2009). An analysis of bicycle route choice preferences in Texas, US. *Transportation*, *36*(5), 511-539.
Shatu, F., Yigitcanlar, T., & Bunker, J. (2019). Shortest path distance vs. least directional change: Empirical testing of space syntax and geographic theories concerning pedestrian route choice behaviour. *Journal of Transport Geography*, *74*, 37-52.
Skov-Petersen, H., Barkow, B., Lundhede, T., & Jacobsen, J. B. (2018). How do cyclists make their way?-A GPS-based revealed preference study in Copenhagen. *International Journal of Geographical Information Science*, *32*(7), 1469-1484.Steer Davies Gleave. (2012). Cycle route choice study. London: Transport for London.
Specht, J. (2014). Tourism and the Built Environment. In *Architectural Tourism* (pp. 7-56). Springer Gabler, Wiesbaden.
Stinson, M. A., & Bhat, C. R. (2003). Commuter bicyclist route choice: Analysis using a stated preference survey. *Transportation research record*, *1828*(1), 107-115.
Sun, G., & Zacharias, J. (2017). Can bicycle relieve overcrowded metro? Managing short-distance travel in Beijing. *Sustainable cities and society*, *35*, 323-330.
Swinburn, B., Egger, G., & Raza, F. (1999). Dissecting obesogenic environments: the development and application of a framework for identifying and prioritizing environmental interventions for obesity. *Preventive medicine*, *29*(6), 563-570.
Tilahun, N. Y., Levinson, D. M., & Krizek, K. J. (2007). Trails, lanes, or traffic: Valuing bicycle facilities with an adaptive stated preference survey. *Transportation Research Part A: Policy and Practice*, *41*(4), 287-301.

Tin, S., Woodward, A., Thornley, S., Langley, J., Rodgers, A., & Ameratunga, S. (2010). Cyclists'attitudes toward policies encouraging bicycle travel: Findings from the Taupo Bicycle Study in New Zealand. Health Promotion International, 25, 54–62.

Ton, D., Cats, O., Duives, D., & Hoogendoorn, S. (2017). How Do People Cycle in Amsterdam, Netherlands?: Estimating Cyclists' Route Choice Determinants with GPS Data from an Urban Area. *Transportation research record*, *2662*(1), 75-82.

Train, K. E. (2009). *Discrete choice methods with simulation*. Cambridge university press.

Van Dyck, D., Cerin, E., Conway, T. L., De Bourdeaudhuij, I., Owen, N., Kerr, J., ... & Sallis, J. F. (2012). Perceived neighborhood environmental attributes associated with adults' transport-related walking and cycling: Findings from the USA, Australia and Belgium. *International Journal of Behavioral Nutrition and Physical Activity*, *9*(1), 70.

Van Holle, V., Van Cauwenberg, J., Deforche, B., Goubert, L., Maes, L., Nasar, J., … De Bourdeaudhuij, I. (2014). Environmental invitingness for transport-related cycling in middle-aged adults: A proof of concept study using photographs. Transportation Research Part A: Policy and Practice, 69, 432–446.

Vedel, S.E., Jacobsen, J.B. & Skov-Petersen, H. (2017). Bicyclists' preferences for route characteristics and crowding in Copenhagen – A choice experiment study of commuters. Transportation Research Part A: Policy and Practice, 100, 53-64.

Verhoeven, H., Van Hecke, L., Van Dyck, D., Baert, T., Van de Weghe, N., Clarys, P., ... & Van Cauwenberg, J. (2018). Differences in physical environmental characteristics between adolescents' actual and shortest cycling routes: a study using a Google Street View-based audit. *International journal of health geographics*, *17*(1), 16.

Wang, Y., Chau, C. K., Ng, W. Y., & Leung, T. M. (2016). A review on the effects of physical built environment attributes on enhancing walking and cycling activity levels within residential neighborhoods. *Cities*, *50*, 1-15.

Yang, C., & Mesbah, M. (2013, October). Route choice behaviour of cyclists by stated preference and revealed preference. In *Australasian Transport Research Forum 2013 Proceedings*.

Wendel-Vos, G. W., Schuit, A. J., de Niet, R., Boshuizen, H. C., Saris, W. H., & Kromhout, D. (2004). Factors of the physical environment associated with walking and bicycling. *Medicine and science in sports and exercise*, *36*(4), 725-730.

Westerdijk, P. K. (1990). Pedestrian and pedal cyclist route choice criteria.

Winters, M., & Teschke, K. (2010). Route preferences among adults in the near market for bicycling: findings of the cycling in cities study. *American journal of health promotion*, *25*(1), 40-47.

Winters, M., Teschke, K., Grant, M., Setton, E. M., & Brauer, M. (2010). How far out of the way will we travel? Built environment influences on route selection for bicycle and car travel. *Transportation Research Record*, *2190*(1), 1-10.

Xie, L., & Spinney, J. (2018). "I won't cycle on a route like this; I don't think I fully understood what isolation meant": A critical evaluation of the safety principles in Cycling Level of Service (CLoS) tools from a gender perspective. *Travel behaviour and society*, *13*, 197-213.

Yáñez, M. F., Raveau, S., & Ortúzar, J. D. D. (2010). Inclusion of latent variables in mixed logit models: modelling and forecasting. *Transportation Research Part A: Policy and Practice*, *44*(9), 744-753.

Zijlema, W. L., Avila-Palencia, I., Triguero-Mas, M., Gidlow, C., Maas, J., Kruize, H., ... & Nieuwenhuijsen, M. J. (2018). Active commuting through natural environments is associated with better mental health: Results from the PHENOTYPE project. *Environment international*, *121*, 721-727.

Appendix A. Observation records preliminary study

Route 1

26 October 2020, 0800

Ride characteristics

Participant id	H
Sex	Male
Age	31
Route origin	Home in De Ruyterstraat - Wipstrik
Route destination	Train station – Assendorp
Shortest path taken	No
Cycling experience	High
Cycling frequency	Daily commute
Route frequency	Takes current route 90% of the time
Alternative routes	2 or 3

Indicated preference

Avoid cars
Avoid tourists and pedestrians
Avoid business in general
Avoid traffic lights
Avoid tunnels

Feel the sun
Pass greenery
During business hours, pass the dike
Pass the water

Observed preference

Takes small paths between houses because it feels exclusive and there is a lower chance of encountering people there
Does not take the small road next to the canal but the big road where cars travel as well because the broad street flows faster
Passes the "Provinciehuis" because it is the shortest route and explicitly names it (landmark)
Very green verges
Mentions nice buildings
Does not cycle trough park the Wezenlanden because there is no thoroughfare (doorgaande weg) in the park and you cannot pass the water
Van Karnebeekweg is a fast flowing street as well, and the old part of the city is avoided because the roads are too small and too busy
Mentions how improvements over the year have made the area more enjoyable
Stadsgracht
Dangerous intersection
Fietsstraat
Avoiding road work
Cycles a different route than when he walks, when he walks he takes the path between houses but when cycling he takes the broader street
Goes over the tracks because the bike facility at the back of the station is better than the one in front
Does not take the tunnel with low elevation difference and takes the bridge with a high elevation difference because of the view and because he cycles the same route every day for 20 years
Does not cycle over a forum because it is a walking area, even though getting of the bicycle and walking takes less time
Mentions how the area has improved since the back of the station has been redefined
Mentions that he likes to take the route that gives him most joy and avoids traffic and traffic lights

Route 2

26 October 2020, 1700

Ride characteristics

Participant id	G
Sex	Male
Age	54
Route origin	Train station – Assendorp
Route destination	Home in Slotenhagenstraat - Stadshagen
Shortest path taken	No
Cycling experience	High
Cycling frequency	Daily commute
Route frequency	Takes current route 75% of the time
Alternative routes	5

Indicated preference

Avoid cars
Avoid schoolchildren
Avoid traffic lights
Cycle along water
Cycle along greenery
Cycle along the train tracks
Avoid road work
Take as many bridges as possible

Observed preference

This route because fast and habit
In the evening he goes along the embankment in case the weather is nice. When it rains, he always takes the fastest route
Bridge that is aesthetic rather than a tunnel
Broad cycling path with water and green
Takes another cycle path which is longer but flows faster and is very broad without cars
Avoids the road with cars but not the path along the train tracks where the maximum speed is 30 km/h
Rather takes route with more elevation difference rather than encountering traffic lights
View is great, you can hear the birds chirping
Good streetlighting in the evening, but after 21 he takes a more populated route
Good perspectives, landmarks everywhere and despite the elevation of the road changing it is not bad, it is a challenge
Water
Liveliness
Gloats that people in cars have to wait at multiple intersections whereas cyclists can cycle undisturbed
Goes out of his way to take the fast cycling path rather than passing houses and small streets where cars are parked which doors can be opened and where the risks of accidents is higher, also due to small children running around
Goes out of his way to take the fast cycle path rather than cycling through a park along water
Takes the fast cycling path because the street is broad and traffic flows undisturbed
Takes a longer route because he passes very diverse houses with different building styles and green gardens rather than a row of VINEX houses
Mentions diversity of sights along the route
Does not take the faster route along the highway because he dislikes cars and prefers cycling through the rich part of Westerholten, an agglomeration of Zwolle, with a mix of houses and much more diverse built environment
Mentions liveliness again
Dangerous intersection
Route goes along the ring road but you never see cars, unlike when you take the faster route

Takes the fastest route home at this moment, otherwise the route takes too long. Cycled 10 min longer than the fastest route would be

Route 3

26 October 2020, 1400

Ride characteristics

Participant id	L
Sex	Male
Age	15
Route origin	Gym - Stadshagen
Route destination	Home in Boogmakersstraat - Stadshagen
Shortest path taken	Yes
Cycling experience	High
Cycling frequency	Daily for all purposes
Route frequency	Three times per week
Alternative routes	2

Indicated preference
Cycling separately from cars
Combining trips; visit shops during route
Avoid people walking over cycle path
Avoid big groups of cyclists or pedestrians

Observed preference
Avoids cyclists and pedestrians on the cycling path on the other side of the water and takes the road where cars and busses drive
Cycles along the park rather than a faster way
Goes along the mall because he wants to do his groceries on the way rather than a faster way
Cycles in walking areas
Refuses to move back to the cycling path after passing the big group of cyclists, says he is too close to his exit on the road (distance is 500 metres)
Passes school to see whether his sister is playing outside

Route 4

27 October 2020, 0915

Ride characteristics

Participant id	O
Sex	Female
Age	16
Route origin	Home in Boekbinderstraat – Stadshagen
Route destination	Deltion College - Holtenbroek
Shortest path taken	No
Cycling experience	High
Cycling frequency	Daily for all purposes
Route frequency	Four days per week
Alternative routes	2

Indicated preference

Avoid cycling parents with kids
Avoid open space in case of wind and rain
Find open space in case of sun
Cycling separately from cars
Pass the petting zoo and their sheep
Pass cafes

Observed preference

Goes along the water rather than over the water which the alternative route does
Many pedestrians and bicyclists on the cycling path
Avoids path designated for walking
Cycles along the embankment, is not the shortest distance but she thinks it is the fastest way, as the alternative routes encounter many cars and intersections etc.
Cycling along the dike brings joy, it is a good start of the day
In the evening she is not allowed by her parents to cycle after 2100, before 2100 she is allowed because the route is busy with pedestrians, cyclists and other sports hobbyists and many people live close to the road. The street lightning is acceptable, one lantern every 50 metres.
Mentions houseboats, cycles along here because she wants to live on one
Mentions diversity of the road, different houses and friends live here
Takes this route also because few cars take the street on the dike
Takes a bridge where just taxi's and busses are allowed, no other cars. The alternative route has a bridge where cars race along you
Mentions the bridge and a red building as landmarks
Chooses another dike after a bridge rather than cycling in the residential area to avoid people and to enjoy the dike for a longer period of time. In the evenings, this part of the dike is not enlightened so she takes the route through the residential area when it is dark
Cycles along the petting zoo and is very excited about it
Mentions she looks for a certain sheep every day
When the cycling path stops, she takes the normal road rather than the pavement which will bring her closer to the cycling facility of the school because the pavement is always busy
Mentions that the area used to be the dumping place for the human trash of the city but it has been gentrified and you can see the difference and that it is becoming a better neighbourhood per each month

Route 5

27 October 2020, 1300

Ride characteristics

Participant id	I
Sex	Male
Age	25
Route origin	Deltion College - Holtenbroek
Route destination	Busstop for bus 83 – Holtenbroek
Shortest path taken	Yes
Cycling experience	High
Cycling frequency	Daily for commuting and intoxicating purposes, otherwise car
Route frequency	Five days per week
Alternative routes	0

Indicated preference
Avoid slower cyclists
Avoid obstructions
Pass supermarket
Generally be fast

Observed preference
Cycles very fast, is irritated by other cyclists
Dark tunnel, takes is because the way above has a traffic light but prefers to cycle above the tunnel when he is not in a hurry
Shortens route by taking the pavement 3 times
Cycles to a bus stop farther away from his school so that he can park a bike in a bicycle facility rather than locking it to a pole or some other thing in the built environment

Route 6

27 October 2020, 1400

Ride characteristics

Participant id	K
Sex	Female
Age	26
Route origin	Work at Pathe cinema – Close to centre
Route destination	Work at the café at Bookshop Waanders – City centre
Shortest path taken	No
Cycling experience	High
Cycling frequency	Daily for all purposes
Route frequency	Thrice per week
Alternative routes	6

Indicated preference

Shortest commute
Avoid walking areas
Cycle along the canals
Find fastest traffic flows

Observed preference

Big time hurry because her shift ran late and she has to get to work in another store, but still wants to take the bridge over the water with traffic lights rather than the faster flowing tunnel
Avoids the city centre because there are many walking people the and cycling around the city is faster than walking through the city
Before corona, she would walk but since corona she does not like to
Goes along the water rather than the fastest way, but also because it is less busy
Points out the historic city walls and expresses joy
Actively goes to a secured bicycle facility rather than an unsecured one closer to work

Route 7
27 October 2020, 1430

Ride characteristics

Participant id	M
Sex	Male
Age	37
Route origin	Waanders – City centre
Route destination	Library/Stadshuiskamer – Assendorp
Shortest path taken	No
Cycling experience	High
Cycling frequency	Daily for all purposes unless distance is further than an hour cycling.
Route frequency	Once per week
Alternative routes	3

Indicated preference
Cycling along the canals
Cycling along the historic city walls
Avoid city centre
Avoid Maagjesbolwerk

Observed preference
Cycles through walking area because there are not many walking there
Straight out of the city centre
Along the canal and green verge, points out cafes
Avoids another walking area because there are pedestrians there
Avoids a road because of its business
Intersection
Does not like the aesthetic of the route but finds the route that is more beautiful too far to consider
Mentions his home, an apartment in Maagjesbolwerk, and cycles past it
Very broad street
Dangerous intersection
Many cars on the road
Along the left canal rather than the heavy car flow route on the other side, which is shorter
Passes de Fundatie
Has to cross the heavily populated car route, then takes some small paths and then relocates to a path along the water

Route 8

27 October 2020, 1500

Ride characteristics

Participant id	J
Sex	Female
Age	21
Route origin	Coffeeshop Sky High – City centre
Route destination	Home in Broerenstraat – City centre
Shortest path taken	No
Cycling experience	High
Cycling frequency	Daily for all purposes
Route frequency	Once per week
Alternative routes	1

Indicated preference

Cycling through the 'fietsstraat'
Avoid the pedestrian areas
Cycling beneath street lighting
Cycling along the Sassenpoort
Cycling along cafes
Cycling along the mansions

Observed preference

Wants to pass the Sassenpoort from the coffee shop because there are not many people there
Big intersection with confusing traffic lights
Passing a bridge
Busy street
Pop up bicycle storage due to corona
Cycles past cafes with terraces, many lights and lively feeling
Cycles in a pedestrian area
Descends from bike after passing the centre square in Zwolle and walks home
Order a pizza for evening meal three hours later
Parks bike in a secured bicycle facility rather than in the street

Route 9
27 October 2020, 1800

Ride characteristics

Participant id	N
Sex	Female
Age	62
Route origin	Work at Xenos - City centre
Route destination	Daycare for grandchild - Wipstrik
Shortest path taken	Yes
Cycling experience	Moderate
Cycling frequency	Four times per week
Route frequency	Once per week
Alternative routes	2

Indicated preference
Cycling along the water
Cycling along houseboats
Cycling along creative spaces
Avoiding tourists on the historic city walls
Avoiding cars leaving the parking garage
Cycling next to beautiful manors along the canals

Observed preference
Avoids roads with cars and busses
Points out houses along the way
Passes two bridges
Takes the longer way around over the street rather than cutting through a small park
Takes a really small cycling path along the embankment and multiple houseboats
Points out pretty lights that houseboats have strung up
Mentions that she rather cycles here with a small change of falling in the water rather than on the other side where the road is shared with cars and busses
Immediately cycles into the residential area rather than the broad way shared with all traffic
Does not take the small one-way roads because she thinks there is a lack of space due to cars parked along the pavement, therefore she chooses small paths between apartment blocks and other houses
Avoids the playground, otherwise her grandchild will want to play there and she has no time
Parks bike far from the day care because all parents crowd the gates of the preschool

Route 10
29 October 2020, 0830

Ride characteristics

Participant id	B
Sex	Female
Age	50
Route origin	Home – Stadshagen
Route destination	Nieuwe Haven – Close to city centre
Shortest path taken	No
Cycling experience	High
Cycling frequency	Daily for all purposes with the city of Zwolle
Route frequency	Thrice a week
Alternative routes	5

Indicated preference
Fastest path in the morning, scenic path in the evening
Find shelter from the weather
Be able to do groceries on the way
Avoid trees due to hay fever
Keep to the area's that are well lit
Avoid traffic lights

Observed preference
States that there is just one way out of Stadshagen to the city, the way that everyone cycles
Takes a slight detour to drop off a letter at her church
Crossing of road just for cars
Cycles along the road for cars on a service road because it is the fastest route
She sometimes takes the greener route but only when she has time to spare since it takes five minutes longer
Mentions that the neighbourhood has changed immensely, what used to be green fields is now a residential area
She used to take the green, dwindling route but since the corona crisis, many people are walking there and blocking the way so she chooses to cycle around it
You can also go over the dike, but it takes a longer time and there are tractors there and she has to get to work so she takes a faster route and choose a later dike ascent
Broad cycling path along green fields with football goals and art
Points to the mall where she buys her groceries on the way home
Mentions that in Stadshagen you are almost forced to cycle, because with the car you always have to take the ring road because parts of the neighbourhood are not connected
Chooses the bridge for taxi's and busses and cyclists because the Hanos bridge has too much noise from cars and she dislikes the atmosphere
Dike again, mentions that it clears her head to cycle here but in the evening its very dark with no street lightning so she either asks her husband to pick her up or she cycles through the residential area
Feels like the route passes water and green so she very much likes to cycle here, points out the sheep, it is like an outing whereas when you cycle through residential areas; you are busy with your work and such things
End of cycling path, you have to cycle over the street
Mentions that the neighbourhood has changed and that the new construction feels much safer than the old flats
Many cyclists who all follow the same path, while there is no cycle path and there are no markings
Tunnel

Exit of the motorway
Roundabout with right of way for cyclists
Follows the canal
Mentions that she can also take another route but that the route is not even a possibility in her head because she has lived in Zwolle for a long time and this is her usual way. A friend of hers cycles it daily, but she thinks that very few people take the route
Nice cityscape of Zwolle
Cycling path along busy ringroad around the city centre
Cycles over the parking place rather than around the building
Points out art on the buildings

Route 11

29 October 2020, 1115

Ride characteristics

Participant id	Q
Sex	Male
Age	41
Route origin	Nieuwe Haven – Close to city centre
Route destination	Anna Heerkens – Assendorp
Shortest path taken	Yes
Cycling experience	High
Cycling frequency	Daily
Route frequency	Twice per week
Alternative routes	1

Indicated preference

Avoid cars
Pass the canal
Pass trees for shelter
Fastest way possible

Observed preference

Indicates that we only have ten minutes to cycle between the his two appointments so we have to hurry
Ring road
Traffic light to cross the ring road
Green verges with many trees and grass
Canal
Road with mixed traffic and no separate cycling path
Exit into residential area with small roads, parked cars
He is angry because the cars keep him waiting while he has right of way

Route 12

29 October 2020, 1715

Ride characteristics

Participant id	R
Sex	Female
Age	29
Route origin	Anna Heerkens – Assendorp
Route destination	Home - Stadshagen
Shortest path taken	No
Cycling experience	High
Cycling frequency	At least four times per week
Route frequency	Twice per week
Alternative routes	3

Indicated preference

Enjoying the ride
Try to cycle along the embankment when it is light, cycle through residential areas when it's dark
Cycling where she can think, open, creative or lively places
Pass as much green as possible

Observed preference

Canal with trees and grass
Cycling behind each other due to all the cars, mixed road without separate cycling path
Mentions that there is another work location further along the canal where she works as well and she likes to work there because she can cycle further along the canal
So much traffic noise
Cycling path
Follows the train track
Takes the 'fietsstraat', broad cycling path with a max speed of 30 hm/h
Very green verges, train tracks are almost invisible
Mentions that you can also cycle on the other side of the tracks but that it is very busy there
Cycling path entirely separate from car road below
Slight change of elevation
Very green verges
Mentions 'eikenprocessierups', so in the time that the caterpillar is there she cycles on the other side of the track
Bridge over the road
Bridge over water along with cars, very noisy
Again separation from cars through elevation
Takes the low bridge into Stadshagen and continues cycling track into Stadshagen
Boring houses, everything is similarly built
Cycles along the dike that separates residential area from the ring road around the city of Zwolle on a mixed traffic road with no cycling path
Very well lit
Mentions that she only takes this route when the weather is nice, otherwise she goes through the city due to shelter
Crosses a busy road
Takes a short detour to pass a tree that is important to her

Route 13

29 October 2020, 1045

Ride characteristics

Participant id	D
Sex	Male
Age	17
Route origin	Home – Stadshagen
Route destination	Thorbecke college – Veldhoek
Shortest path taken	No
Cycling experience	High
Cycling frequency	Daily for all purposes
Route frequency	Daily
Alternative routes	1

Indicated preference

Avoid cars
Fastest way possible
Cycle trough part of the city centre
Avoid traffic lights
Take bridges
Avoid boring routes

Observed preference

Crossing of road just for cars
Green field with art, small cycling path
Mall
Points out city farm
Broad cycling path along green fields with soccer goals and art
Mentions that the cycling path is very busy in the morning, as long as you pass the road before 0800 you are fine, afterwards all preschool kids are cycling on their way to school and you can better take another way if you want to make it to school in time
Takes bridge without cars and not the other because the other is a bit farther away and there are more open places, so there is less shelter
Mentions that you can also take another bridge which he almost never does, except for when the current bridge is opened. Then he races to the walking bridge in order to make it to school in time
Dike
He always cycles along the dike, even when it is dark. Except for in the winter when it freezes, then the dike is way too slippery
Petting zoo
End of cycling path, mixed traffic street
Tunnel
Mentions that he could also have cycled through Holterbroek, but there are many traffic lights there
Roundabout with right of way for cyclists
Bridge crossing into the city centre
Bridge crossing outside the city centre again
Mentions that we went through the city because it avoids the traffic lights and he becomes happy due to the liveliness of the morning hustle and bustle
Road work, cycling over pavement
Many trees and green verges, separate cycling path
Crossing of a 50 km/h street
Residential area with no cycling paths and many parked cars

Tunnel
Separate cycling path from the busy car road
Very busy and noisy route but we have not stopped once
Route crossed two LF paths

Route 14

29 October 2020, 1515

Ride characteristics

Participant id	P
Sex	Male
Age	13
Route origin	Thorbecke College – Veldhoek
Route destination	Home – AA-Landen
Shortest path taken	Yes
Cycling experience	High
Cycling frequency	Daily for all purposes
Route frequency	Daily
Alternative routes	1

Indicated preference

Tries to avoid big intersections with cars
Rather cycles over cycling paths than on residential streets
Built environment does not really matter, more whether the route is fast and which way is the shortest way for him and his friends to ride together

Observed preference

Mentions that he only takes this route because he cycles together with someone, he thinks the route is boring and feels less comfortable
Tunnel
Busy road with cars, cycling path not separate and many roundabouts
Few changes in scenery
Mentions that even though this road is the more logical choice because it is shorter and less busy than the one through the city, he is bored already and wants some diversity even though he constantly talks with his friend
Traffic light
Dark tunnel
Cycling path ends, mixed traffic road
Mall Holterbroek
Cars are everywhere
Street lightning does not work
Much water and trees
Cutting out of residential area and cycling on the dike
Bridge over water for just cyclists, taxi’s and busses
Broad cycling path with art and green fields with soccer goals
Oude Wetering, main cycling route of Stadshagen
Shortcut over the pavement to his house

Route 15

30 October 2020, 1000

Ride characteristics

Participant id	C
Sex	Female
Age	19
Route origin	Home – Stadshagen
Route destination	Home of a friend – AA-Landen
Shortest path taken	No
Cycling experience	High
Cycling frequency	Daily
Route frequency	Once per week
Alternative routes	1

Indicated preference

Likes to pass the forest
Like to pass football fields
Avoids residential areas
Cycles along the IJssel as far as she can

Observed preference

Crossing of road just for cars
Green field with all sorts of walking paths
Roadblock for cars in the road
Lack of noise compared to other routes in Stadshagen
Separate cycling path
Mentions that in case of wind or haste, she cycles through the residential area because it offers shelter from the wind but the downside is that there are curbs in the roads so that car traffic is slowed down, but it is irritating for cycling
Cycling path next to 80 km/h Stadshagen ring road
Much noise
Bridge shared with cars, much noise and tailwind of the cars
Cycling next to a forest
Mentions that she is not allowed to cycle here alone in the evening due to isolation and lack of lighting, if she wants to she has to call her father who will cycle towards her
Separate cycling path but busy road next to it, very much noise
Traffic lights
Park with concrete slabs for a cycling path
Residential area with mixed traffic road
Crossing of big car road
Residential area with mixed traffic road
Green dike-like separation from the main road
Residential area

Route 16
30 October 2020, 1500

Ride characteristics

Participant id	F
Sex	Female
Age	16
Route origin	Bicycle shop in AA-Landen
Route destination	Home of a friend in Stadshagen
Shortest path taken	Yes
Cycling experience	High
Cycling frequency	Daily
Route frequency	Two times per month
Alternative routes	1

Indicated preference
Cycles trough residential areas when it is windy
Usually avoids residential areas due to sidewalk-edges in the street to slow car traffic
Likes the forest
Avoids streets without separate cycling tracks
Prefers trees over street lighting

Observed preference
Green roundabout
Cycling path on the road with big traffic
Residential area with mixed traffic road and parked cars
Green dike-like separation from the main road
Residential area with mixed traffic road and parked cars
Park with concrete slabs for a cycling path
Traffic lights
Separate cycling path but busy road next to it, very much noise
Broad cycling path along the edge of a forest, very few street lighting
Bridge shared with cars, much noise and tailwind of the cars
Direct exit into the residential area
Shared road for all traffic
Many parked cars
Cutting between two streets by cycling through a courtyard between houses
Curbs everywhere in the street
Dwindling roads
Feels like the built environment is focused on slowing people down, cars as much as cyclists
Crossing of busy road
Residential area with mixed traffic road, few cars parked
Green verges everywhere
Trees everywhere

Route 17

31 October 2020, 1600

Ride characteristics

Participant id	A
Sex	Male
Age	50
Route origin	Home in Stadshagen
Route destination	Milligerplas in Stadshagen
Shortest path taken	Yes
Cycling experience	High
Cycling frequency	Daily
Route frequency	Two times per week
Alternative routes	1

Indicated preference

Avoid double timing roads
Feel the weather and the sun in your face
Avoid residential areas due to running children
Avoid residential areas due to parked cars
Broad cycling paths

Observed preference

The weather is stormy, heavy wind and rain
Cycles along the Halloween themed house rather than immediately cycling to the green dike
Does go to the dike with sheep after the Halloween house, mentions that the house changes some part of its decoration every day and that he likes to look daily to spot the differences
Mentions that the number of sheep has increased this year, which he likes
Roundabout where cyclists do not have right of way, unlike almost the entire other cycling infrastructure in Zwolle
States that he usually cycles along the Oude Wetering, however that route is very exposed and today it is raining too heavy and the wind will be severe, therefore he cycles through the residential area
Drops a letter of at his tennis club
Mentions that he dislikes this route because you feel like you double time a lot of distance by having to cycle between bridges etcetera
Mentions that he likes that he has to stall his bike in a wooden post bicycle facility rather than an iron one

Appendix B. Participant letter

Geachte heer of mevrouw,

Allereerst hartelijk dank voor het meedoen aan ons onderzoek.

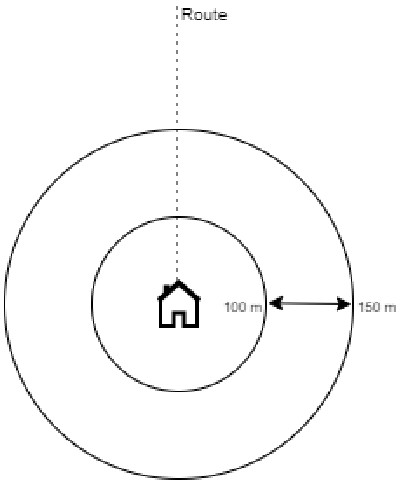
In deze brief vindt u een handleiding voor het gebruik van de GPS-trackers.

Wat we aan u vragen is het volgende:

- De GPS-tracker een week lang bij u te dragen; het maakt niet uit of u hem in uw zak of tas stopt.
- De GPS-tracker iedere dag op te laden; hiervoor ontvangt u een oplaadkabel.
- Achteraf de naar u gestuurde enquête in te vullen.

We benadrukken dat uw privacy goed gewaarborgd wordt:

- Uw data wordt automatisch verstuurd naar een centrale server waartoe alleen onze begeleider toegang tot heeft.
- Onze begeleider anonimiseert de GPS-ritten door de routes op ongeveer 100 tot 150 meter van uw huisadres te laten stoppen. Daardoor is het onmogelijk om uw huisadres te traceren. We weten alleen dat het ergens op 100 tot 150 meter afstand van het eind van de route ligt. Dit is zichtbaar in de afbeelding. Voor ons lijkt het alsof uw huis ergens in de buitenste ring staat terwijl uw huis daadwerkelijk in het midden van de cirkel staat.
- Wij hebben geen toegang tot de originele data; die wordt door onze begeleider verwijderd.
- In lijn met richtlijnen van het rijk, heeft onze begeleider een privacyverklaring getekend. Onderzoekers hebben geen enkel belang bij individuele data, maar kijken alleen naar patronen van de hele groep.
- De data wordt niet doorgegeven aan derden.



Bij vragen kunt u altijd contact opnemen met de persoon van wie u de tracker heeft ontvangen.

- Harmke Vliek:
  g.h.vliek@students.uu.nl
  0611689821
- Jimme Smit:
  j.smit6@students.uu.nl
  0616374277
- Maaike Kuiper:
  m.d.kuiper2@students.uu.nl
  0623407886

Bij voorbaat dank en veel fietsplezier!

Appendix C. Participant survey

Geachte heer of mevrouw,

Wij zijn studenten aan de Universiteit Utrecht en de TU Delft. Wij doen onderzoek naar fietsroutekeuze. Hiervoor vragen wij u om uw fietsverplaatsingen bij te houden met een zogeheten GPS-tracker. Ook vragen wij u of u deze enquête wilt invullen.

In deze enquête stellen wij u een aantal vragen die ons helpen om uw fietsverplaatsingen te begrijpen. De vragen gaan over de frequentie van uw fietsgedrag en uw voorkeuren met betrekking tot de omgeving waarin u fietst tijdens uw route. Tot slot zullen er nog wat persoonskenmerken gevraagd worden. Uw gegevens worden vertrouwelijk behandeld en volledig anoniem verwerkt, zoals we beschreven hebben in de brief. Het invullen van de enquête vraagt ongeveer 15 minuten van uw tijd.

Alvast hartelijk bedankt voor uw medewerking!

---

1. GPS tracker identificatienummer (vermeld op de achterzijde van de tracker, wanneer u deze uit de hoes haalt):

De volgende vragen gaan over uw fietsgewoonten voordat de corona crisis uitbrak.

2. Voor welke doelen gebruikt u een fiets (voor de corona crisis)? (meerdere antwoorden mogelijk)
   - ▢ Woon-werkrit
   - ▢ Zakelijk: ritten tijdens werk
   - ▢ School of studie
   - ▢ Voorzieningen bezoeken (winkels, supermarkten en dergelijke)
   - ▢ Recreatief
   - ▢ Sport
   - ▢ Vrienden of familie bezoeken
   - ▢ Overig

3. Wat voor soort fiets(en) heeft u?
   - ▢ Stadsfiets zonder versnellingen
   - ▢ Stadsfiets met versnellingen
   - ▢ Sportieve fiets (hybride)
   - ▢ Racefiets
   - ▢ Mountainbike
   - ▢ Elektrische fiets (max. 25 km/uur)
   - ▢ Speed pedelec (max. 45 km/uur)
   - ▢ Ligfiets
   - ▢ Vouwfiets
   - ▢ Tandem
   - ▢ OV-fiets
   - ▢ Anders, namelijk

4. Indien u meerdere fietsen heeft, voor welk doel gebruikt u elke fiets? Selecteer de doelen waarvoor u fietst en selecteer het soort fiets dat u daarvoor gebruikt

	Woon-werkrit	Zakelijk	School of studie	Voorzieningen bezoeken	Recreatief	Sport	Vrienden of familie bezoeken	Overig
Stadsfiets zonder versnellingen	○	○	○	○	○	○	○	○
Stadsfiets met versnellingen	○	○	○	○	○	○	○	○
Sportieve fiets (hybride)	○	○	○	○	○	○	○	○
Racefiets	○	○	○	○	○	○	○	○
Mountainbike	○	○	○	○	○	○	○	○
Elektrische fiets (max. 25km/uur)	○	○	○	○	○	○	○	○
Speed pedelec (max. 45km/uur)	○	○	○	○	○	○	○	○
Ligfiets	○	○	○	○	○	○	○	○
Vouwfiets	○	○	○	○	○	○	○	○
Tandem	○	○	○	○	○	○	○	○
Ov-fiets	○	○	○	○	○	○	○	○
Overig	○	○	○	○	○	○	○	○

5. Wat is de onderhoudsstaat van uw meest gebruikte fiets?

- ☐ Uitstekend onderhouden
- ☐ Goed onderhouden
- ☐ Gemiddeld
- ☐ Minder goed onderhouden
- ☐ Niet onderhouden

6. Op welke leeftijd bent u zelf gaan fietsen in de openbare ruimte (Vul alleen het getal in)?

7. Hoe vaak fietst u?

- ☐ Dagelijks
- ☐ Ongeveer ____ dagen per week
- ☐ Ongeveer ____ dagen per maand
- ☐ Zelden
- ☐ Nooit

8. Welke afstand fietst u ongeveer voor de volgende bestemmingen (indien van toepassing)?

- ☐ Werk: … km
- ☐ School/studie: … km
- ☐ Boodschappen: … km
- ☐ Naar openbaar Vervoer: … km

9. Geef uw voorkeuren aan in de volgende uitspraken

Kruis aan in hoeverre u het eens bent (bedenk dat het anoniem is)

	Helemaal oneens		Neu-traal		Helemaal eens
9.1 Ik fiets graag langs het *water*, ook als dit niet de kortste route is.	○	○	○	○	○
9.2 Ik fiets graag door het *park*, ook als dit niet de kortste route is.	○	○	○	○	○
9.3 Ik fiets graag door het *bos*, ook als dit niet de kortste route is.	○	○	○	○	○
9.4 Fietsen door een mooie omgeving is voor mij belangrijk, ook als dit niet de kortste route is.	○	○	○	○	○
9.5 Ik fiets graag via een levendige route, ook als dit niet de kortste route is.	○	○	○	○	○
9.6 Ik fiets graag langs herkenningspunten zoals kunstwerken of gebouwen door een interessante stedelijke omgeving.	○	○	○	○	○
9.7 Met slecht weer zoek ik een beschutte route.	○	○	○	○	○
9.8 Ik vermijd het liefst een lawaaiige omgeving, bijvoorbeeld van verkeer.	○	○	○	○	○

	Helemaal oneens		Neu-traal		Helemaal eens
9.9 Als het schemert of donker is, neem ik graag een route met goede straatverlichting.	○	○	○	○	○
9.10 Ik vermijd verkeerslichten zo veel mogelijk.	○	○	○	○	○
9.11 Ik vermijd drukke kruispunten zo veel mogelijk.	○	○	○	○	○
9.12 Ik fiets liever op fietspaden die gescheiden zijn van de weg.	○	○	○	○	○
9.13 Ik vermijd verkeersdrukte.	○	○	○	○	○
9.14 Ik fiets liever op wegen waar de maximale snelheid voor auto's 30 km/u is.	○	○	○	○	○
9.15 Ik vermijd onveilige routes, ook als dit niet de kortste route is.	○	○	○	○	○
9.16 Ik houd rekening met sociale veiligheid in mijn routekeuze.	○	○	○	○	○
9.17 Ik houdt rekening met kans op diefstal als ik mijn fiets parkeer	○	○	○	○	○
9.18 Ik vermijd verlaten gebieden, ook als dit niet de kortste route is.	○	○	○	○	○
9.19 Ik vermijd wegwerkzaamheden.	○	○	○	○	○

	Helemaal oneens		Neu-traal		Helemaal eens
9.20 Als ik fiets dan probeer ik de kortste route te nemen.	○	○	○	○	○
9.21 Als ik fiets dan probeer ik de reistijd zo kort mogelijk te houden.	○	○	○	○	○
9.22 Als ik fiets dan probeer ik zo veel mogelijk te fietsen zonder te hoeven stoppen (verkeerslichten bijvoorbeeld).	○	○	○	○	○
9.23 Als ik fiets dan probeer ik een hoog tempo aan te houden.	○	○	○	○	○
9.24 Als ik fiets neem ik wel eens doorsteekjes om een deel van de route af te snijden.	○	○	○	○	○
9.25 Ik fiets nooit door een rood stoplicht.	○	○	○	○	○

	Helemaal oneens		Neu-traal		Helemaal eens
9.26 Ik vind fietsen ontspannend.	○	○	○	○	○
9.27 Ik zie mijzelf als iemand met een goede conditie.	○	○	○	○	○
9.28 Ik vind een e-bike duur.	○	○	○	○	○
9.29 Ik vind een e-bike het geld waard.	○	○	○	○	○

De volgende vragen gaan over de mogelijke verandering van uw fietsgedrag met betrekking tot de corona crisis.

10. Werkt u thuis vanwege de corona crisis?
- ☐ Ja
- ☐ Nee
- ☐ Gedeeltelijk
- ☐ Niet van toepassing

11. Voor welke doelen gebruikt u de fiets (voor de corona crisis)? *(meerdere antwoorden mogelijk)*
- ☐ Woon-werkrit
- ☐ Zakelijk: ritten tijdens het werk
- ☐ School of studie
- ☐ Voorzieningen bezoeken (winkels, supermarkten en dergelijke)
- ☐ Recreatief
- ☐ Sport
- ☐ Vrienden of familie bezoeken
- ☐ Overig

12. Is uw fietsgedrag met betrekking tot **werk of school** veranderd sinds de coronacrisis?
- ☐ Ja, ik fiets meer
- ☐ Ja, ik fiets minder
- ☐ Nee
- ☐ Niet van toepassing

13. Is uw **recreatieve** fietsgedrag veranderd sinds de coronacrisis?
- ☐ Ja, ik fiets meer
- ☐ Ja, ik fiets minder
- ☐ Nee
- ☐ Niet van toepassing

14. Vermijdt u sinds de coronacrisis drukke fietsroutes?
- ☐ Ja
- ☐ Nee
- ☐ Af en toe
- ☐ Niet van toepassing

Ten slotte vragen we u enkele persoonlijke gegevens. Uw gegevens worden anoniem verwerkt.

15. Wat is uw geboortejaar?

16. Wat is uw geslacht?
- ☐ Vrouw
- ☐ Man
- ☐ Anders / wil ik niet zeggen

17. Wat is uw hoogste opleiding?
- ☐ Lbo, mulo, mavo, vmbo of gelijkwaardig
- ☐ Havo, vwo, mms, hbs, mbo of gelijkwaardig
- ☐ Hbo of universiteit
- ☐ Anders

18. Wat is de samenstelling van uw huishouden?

- ☐ Alleenstaand *zonder* thuiswonende kinderen
- ☐ Alleenstaand *met* thuiswonende kinderen op de basisschoolleeftijd of jonger
- ☐ Alleenstaand *met* thuiswonende kinderen op de middelbare schoolleeftijd of ouder
- ☐ Samenwonend/gehuwd *zonder* thuiswonende kinderen
- ☐ Samenwonend/gehuwd *met* thuiswonende kinderen op de basisschoolleeftijd of jonger
- ☐ Samenwonend/gehuwd *met* thuiswonende kinderen op de middelbare schoolleeftijd of ouder
- ☐ Samenwonend met andere volwassenen *(zoals studentenhuis, zorgcentrum of woongroep)*
- ☐ Thuiswonend bij ouder(s) of pleegouder(s)

19. Wat is uw (belangrijkste) dagelijkse bezigheid?

- ☐ Betaald werk, voltijd
- ☐ Betaald werk, deeltijd (minder dan 36 uur/week)
- ☐ School/studie
- ☐ Geen betaald werk, gepensioneerd, vrijwilligerswerk, overig

20. Wat is het netto inkomen van uw huishouden per maand? (als u samenwonend/gehuwd bent, beide inkomens tezamen).

- ☐ Minder dan € 2000
- ☐ Tussen € 2000 en € 4000
- ☐ Tussen € 4000 en € 6000
- ☐ Meer dan € 6000
- ☐ Dat weet ik niet / dat wil ik niet zeggen

21. In welk type woning woont u?

- ☐ Vrijstaand
- ☐ Twee onder een kap
- ☐ Rijwoning
- ☐ Boven- of benedenwoning
- ☐ Portiekwoning, flat, appartement
- ☐ Anders

22. Beschikt u over een auto?

- ☐ Ja, altijd
- ☐ Ja, maar in overleg
- ☐ Nee

We willen graag een indruk van de gebouwde omgeving rond uw woning en werk, daarvoor gebruikten wij de postcode. Dit is niet herleidbaar tot uw woning.

23. Wat is de postcode van uw woning? (XXXX AB)

24. Wat is de postcode van uw werk? (XXXX AB)

---

25. Heeft u nog opmerkingen of suggesties?

Appendix D. Python file for GPS point separation into routes

Appendix D provides the python script that separates all GPS points into GPS points that form a separate route.

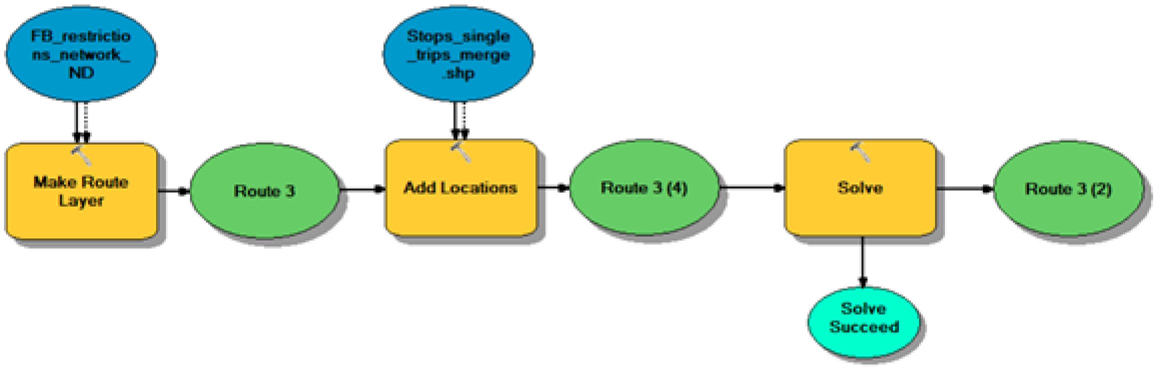
```
import csv
import numpy

# open csv file with GPS points
a = []
description = ["imei,time,lng,lat,angle,speed,altitude"]
route = [description]
name = "resultsTXX_X_01.csv"
inputname = "ResultsT21_4.csv"

# create list containing all data
data = list(csv.reader(open(inputname)))
name = name[:8] + inputname [8:12] + name[12:]

# remove points with a speed <5 km/h
for i in range(len(data)):
    if i == 0:
        i += 1
    else:
        if int(data[i][5]) <= 5:
            i += 1
        else:
            a.append(data[i])
            i += 1

# cycle trough all data
for j in range(len(a)):
    if j == len(a)-1:
        route.append(a[j])
        # set up variables to determine speed cutoffs
        totalspeed = 0
        maxspeed = 0
        for k in range(len(route)-1):
            totalspeed += int(route[k+1][5])
            if int(route[k+1][5]) > maxspeed:
                    maxspeed = int(route[k+1][5])
        avgspeed = totalspeed / (len(route)-1)

        # least amount of points to form a route is 20; select speed cutoffs
        if len(route) > 20 and avgspeed < 30 and avgspeed > 10 and maxspeed
< 40:
            with open(name, 'w', newline='', encoding='utf-8') as csv_file:
                writer = csv.writer(csv_file, delimiter=',')
                writer.writerows(route)

            # name route
            tempname = int(name[13:15])+1
            if tempname < 10:
                print(name)
                name = name[:14] + str(tempname) + name[15:]

            else:
                name = name[:13] + str(tempname) + name[15:]
```

```
    else:
        # annotate date and time of gps points
        datetime1 = a[j][1]
        date1 = (datetime1[:10])
        time1 = (datetime1[11:])

        datetime2 = a[j+1][1]
        date2 = (datetime2[:10])
        time2 = (datetime2[11:])

        Y1= int(date1[:4])
        m1= int(date1[5:7])
        d1= int(date1[8:10])
        H1= int(time1[:2])
        M1= int(time1[3:5])
        S1= int(time1[6:8])

        Y2= int(date2[:4])
        m2= int(date2[5:7])
        d2= int(date2[8:10])
        H2= int(time2[:2])
        M2= int(time2[3:5])
        S2= int(time2[6:8])

        timedifference = (S2+(60*M2)+(3600*H2))-(S1+(60*M1)+(3600*H1))

        # Determine a new route if more than 5 minutes between two gps points
in a similar place
        if abs(timedifference) > 300:
            route.append(a[j])
            totalspeed = 0
            maxspeed = 0
            for k in range(len(route)-1):
                totalspeed += int(route[k+1][5])
                if int(route[k+1][5]) > maxspeed:
                    maxspeed = int(route[k+1][5])
            avgspeed = totalspeed / (len(route)-1)

            # least amount of points to form a route is 20; select speed
            cutoffs
            if len(route) > 20 and avgspeed < 30 and avgspeed > 10 and
            maxspeed < 40:
                with open(name, 'w', newline='', encoding='utf-8') as
                csv_file:
                    writer = csv.writer(csv_file, delimiter=',')
                    writer.writerows(route)
                tempname = int(name[13:15])+1
                if tempname < 10:
                    print(name)
                    name = name[:14] + str(tempname) + name[15:]

                else:
                    name = name[:13] + str(tempname) + name[15:]
            route = [description]

        else:
            route.append(a[j])
```

Appendix E. Greenest route alternative development

To determine the greenest route; the cost of cycling along the spatial indicators water, greenery and aesthetics must be balanced with the cost of additional distance to the trip. Figure D.1 shows the vector model made with ModelBuilder in ArcMap 10.7. The first row depicts the input of the tools, whereas the second layer visualizes the operations performed on the input data. The third row depicts the output of the model.

Figure E.1 Model greenest route determination



The model starts with the creation of a route layer based on the input network "FB_restriction_network_ND". This network is created based on the Fietsersbond dataset, converting it from a shapefile to a network dataset with ArcCatalog 10.7. This network is turned into the layer *Route 3,* after which stops are inserted into the route layer with the function Add Locations. These locations are the origin and destination points of all observed trips, which are converted from point files to stops in ArcGIS Pro before they are added to the model; and stored in the file "Stops_all_trips" represented by the blue oval. The conversion of the points is done in a separate program because it offers the option of importing stops based on route names rather than selecting the stops manually.

The route layer is then updated; containing both the network and the origin and destination points of each trip and stored as *Route 3 (4).* This route layer is the input for the function *Solve,* where each origin and destination pair is connected across the network based on a hierarchy of lines within the network. The network contains restrictions for certain lines; where water, greenness of the environment and aesthetics of the environment determine which route is generated. The restrictions are defined so that a route line is less costly when it is located in proximity to water, similar to the manner in which a green and aesthetically pleasing environment are less costly than ugly and built environment. Table D.1 provides the restrictions and the cost of moving along a route segment that contains the cost value. The *Solve* function finds the least costly option along the network between the origin and destination points, thereby weighing distance as a cost as well.

Table E.1 Restrictions on route segments

Greenery: avoid low	
NO DATA	0
BE (no green)	1
BE (much green)	2
Meadows	3
Rustic	4
Forest	5
Nature	6

Aesthetic: prefer high	
Displeasing	-2
Boring	-1
Neutral	0
Scenic	1
Picturesque	2

Water: prefer high	
No	0
Yes	1

After the completion of the *Solve* function, there are two outputs. The first outcome is the message *Solve Succeed.* This message means that routes have been generated for each input origin and destination pair. The second outcome is a new route layer called *Route 3 (2),* which contains the greenest routes stored in a single attribute table. This route layer is then manually split per route with the *Split by Attributes* function. These routes are then processed according to the research methodology in Chapter 4. The generation of the other alternatives occurs in a similar manner but with different restrictions, as described in appendix E.

Appendix F. Network restrictions generated alternative routes

Appendix F provides an overview of the costs and restrictions based upon which the alternative routes are generated. Each route considers length as a cost, thereby avoiding long winding routes that are implausible due to a low valuation of route segments for the specific restrictions that are placed on each route. Each alternative is generated with different restrictions, which are provided in the tables below. Table E.1 provides the restrictions for the shortest routes, which are none. Table E.2, E.3 and E.4 subsequently provide the restrictions for the socially safe route, the fast route, and the traffic safe route.

Shortest route

Table F.1 Cost on shortest route segments

Length: Cost
Choose least amount of metres

Socially safe route

Table F.2 Restrictions on socially safe route segments

Environment: prefer medium	
NO DATA	0
meadows	1
BE (no green)	2
BE (much green)	3
Forest	4
Rustic	5
Nature	6

Streetlight: prefer high	
NO DATA	0
Poorly lit	1
Medium lit	2
Well lit	3

Criminality: prefer low
Criminality value

Fast route

Table F.3 Restrictions on fast route segments

Traffic lights: prefer low
Number of traffic lights

Stops: prefer low
Number of stops

Intersections: prefer low
Number of intersections

Traffic safe route

Table F.4 Restrictions on traffic safe route segments

Road type: prefer high	
NO DATA	0
Scooter lane	1
Bicycle lane	2
Separated cycling boulevard	3
Mixed road	4
Separated scooter path	5
Separated cycling path	6
Pedestrian passage	7

Speed: prefer low	
Safe	1
Unsafe	2

Accidents: prefer low
Number of accidents

Streetlight: prefer high	
NO DATA	0
Poorly lit	1
Medium lit	2
Well lit	3

Appendix G. Python code for environment variables

Appendix G provides the python code for the environment variables of each alternative; in this case the observed route. Since the script is similar for each alternative, just the observed route file is added. The code is divided into four separate files that interact.

G.1 script for variables daylight and precipitation

```
# convert excel for weather and daylight into spatial attributes
import pandas as pd
import numpy as np

# set up file and dataframes
import os
filenames = []
for f in os.listdir():
    if f.endswith(".csv"):
        filenames.append(f)
dataframes = [pd.read_csv(f, delimiter=',') for f in filenames]
tracker_df = []
for df, name in zip(dataframes, filenames):
    df.insert(1, "Route", f"{name[7:-4]}")
    tracker_df.append(df)
final_df = pd.concat(tracker_df).reset_index(drop=True)
final_df

# select data to add to the spatial attribute file
data = final_df.loc[:, ["Route"]]
data["Datum"] = final_df.time.str[:10]
data["Tijd"] = final_df.time.str[11:]
data

# select time data to add to the spatial attribute file
data2 = data.loc[:, ["Route", "Datum", "Tijd"]]
data2["Hour"] = data.Tijd.str[:2]
data2

# convert time to readable format
data2["Hour"] = data2["Hour"].astype("str").astype("float").astype("int")
data2.dtypes

# select value of darklight variable based on time
data2["darklight"] = np.where((data2["Hour"] >= 8) & (data2["Hour"] <= 17),
"light", "dark")
data2

# create dummy variables
dum = pd.get_dummies(data2.loc[:, "darklight"])
dum.insert(0, "Route", data2["Route"])
dum

# group dummies per route
dum.groupby(["Route"]).sum()

# convert darklight variable to 0 and 1
route3 = data2.loc[:, ["Route", "Datum", "Tijd"]]
route3["Tijdstip"] = np.where(dum["light"] > dum["dark"], 1, 0)
route4 = route3.groupby("Route").mean()
route4
```

```
# set up weather variable
route5 = data2.groupby(["Route", "Datum"]).mean()
del route5["Hour"]
route5.reset_index(level = 1, inplace = True)

tr = route5.join(route4, how="outer")
tr['Datum'] =  pd.to_datetime(tr['Datum'], infer_datetime_format = False )
tr["Datum"] = tr["Datum"].dt.strftime("%d-%m-%Y"
tr

# open csv file containing weather data
dr = pd.read_csv("Weer/Weer.csv")
dr["Datum"] = pd.to_datetime(dr["Datum"])
dr["Datum"] = dr["Datum"].dt.strftime("%d-%m-%Y")
dr

# join weather information in one row
x = dr.groupby("Datum").sum()
x
result = tr.join(x, on=["Datum"])
result

# write excel output file containing weather and daylight variables
result.to_csv("Weer/Donkerlicht_Weer.txt")
```

G.2 script for spatial variables that are added after the first spatial join in ArcGIS Pro

```
# load in variables that are not joined in the first spatial join in ArcGIS
Pro
import pandas as pd
import numpy as np

# create dataframe
pd.set_option('display.max_column', None)
pd.set_option('display.max_rows', None)

# select data
import os
filenames = []
for f in os.listdir():
    if f.endswith(".txt"):
        filenames.append(f)
dataframes = [pd.read_csv(f, delimiter=";") for f in filenames]
tracker_df = []
for df, name in zip(dataframes, filenames):
    df.insert(0, "Route", f"{name[3:11]}")
    df.insert(1, "TrackerID", f"{name[3:8]}")
    tracker_df.append(df)
final_df = pd.concat(tracker_df).reset_index(drop=True)

final_df.iloc[:, 4:] = final_df.iloc[:, 4:].convert_dtypes()
final_df.iloc[:, 4:] = final_df.iloc[:, 4:].apply(lambda x:
x.str.replace(",", "."))
final_df.iloc[:, 4:] = final_df.iloc[:, 4:].apply(lambda x:
x.astype("float").astype("int"))
final_df

# set up temp variable to load spatial variables
spatjoin = final_df.iloc[:, :1]
```

```
spatjoin["Ongevallen"] = final_df.iloc[:, 5].astype(str).astype(int)
spatjoin["StopBordenLicht"] = final_df.iloc[:, 6].astype(str).astype(int)
spatjoin["Bruggen"] = final_df.iloc[:, 7].astype(str).astype(int)
spatjoin["Misdaadcijfers"] = final_df.iloc[:, -1].astype(str).astype(int)
spatjoin

# select specific data values for spatial variables
spatjoin = final_df.iloc[:, :1]
spatjoin["Ongevallen"] = final_df.iloc[:, -4].astype(str).astype(int)
spatjoin["StopBordenLicht"] = final_df.iloc[:, -3].astype(str).astype(int)
spatjoin["Bruggen"] = final_df.iloc[:, -2].astype(str).astype(int)
spatjoin["Misdaadcijfers"] = final_df.iloc[:, -1].astype(str).astype(int)
spatjoin

# set up output frame
output = spatjoin.groupby(["Route"]).mean()
output

# write csv file for output:
output.to_csv("SpatialJoinfile.txt")
```

G.3 script adding all environment variables together

```
import pandas as pd
import numpy as np

# create dataframe
pd.set_option('display.max_column', None)
pd.set_option('display.max_rows', None)

import os
filenames = []
print(os.getcwd())
for f in os.listdir():
    if f.endswith(".txt"):
        filenames.append(f)
dataframes = [pd.read_csv(f, delimiter=";") for f in filenames]
tracker_df = []
for df, name in zip(dataframes, filenames):
    df.insert(0, "Route", f"{name.split('.')[0]}")
    df.insert(1, "TrackerID", f"{name[:5]}")
    df.insert(2, "numberoflinks", f"{len(df)}")
    tracker_df.append(df)
final_df = pd.concat(tracker_df).reset_index(drop=True)
del final_df["Shape_Le_1"]
final_df.iloc[:, 66:-2] = final_df.iloc[:, 66:-2].convert_dtypes()
final_df.iloc[:, 66:-2] = final_df.iloc[:, 66:-2].apply(lambda x:
x.str.replace(",", "."))
final_df.iloc[:, 66:-4] = final_df.iloc[:, 66:-4].apply(lambda x:
x.astype("float").astype("int"))
final_df["Shape_Leng"] = final_df["Shape_Leng"].convert_dtypes()
final_df["Shape_Leng"] = final_df["Shape_Leng"].str.replace(",",
".").astype("float").apply(lambda x: round(x, 2))
final_df["length"] = final_df["length"].astype("float").apply(lambda x:
round(x, 2))
final_df

# check for missing values
final_df[final_df.isnull().any([axis=1])]
```

```
# create variable for percentage calculations for spatial variables
final_df["Routeperc"] = ((final_df["Shape_Leng"] / final_df["length"]) *
100).apply(lambda x: round(x, 2))
final_df


# prepare dummies for calculations
pd.get_dummies(final_df, prefix="", prefix_sep="")

# load data from arcgis pro output files
x = pd.get_dummies(final_df.loc[:, ["WEGNIVEAU", "WEGTYPE", "WEGDEKSRT",
"OMGEVING", "VERLICHTIN", "MAXSNELHEI", "KRP_TYPE"]])
x.insert(0, "Route", final_df["Route"])
x.insert(1, "TrackerID", final_df["TrackerID"])
x.insert(2, "numberoflinks", final_df["numberoflinks"])
x

# create dataframe for sum of tracks per route
frame1 = x.groupby(["Route", "TrackerID", "numberoflinks"]).sum()
frame1.reset_index(level = 2, inplace = True)
frame1.reset_index(level = 1, inplace = True)
frame1

# load variables
y = final_df.loc[:, ["Route", "TrackerID", "WEGKWAL2", "HINDER2",
"SCHOONH2", "VERLICHT2"]].groupby(["Route"]).mean()

# group variabes to make 1 row instead of all input rows
frame2 = y.groupby(["Route"]).mean()
frame2.iloc[:, :4] = frame2.iloc[:, :4].apply(lambda x: round(x, 2))
frame2

# calculate percentages spatial variables
z = final_df.loc[:, ["Route", "WATER2", "SNELFIETS2", "Routeperc"]]
z["Waterperc"] = z["WATER2"] * z["Routeperc"]
z["Snelfperc"] = z["SNELFIETS2"] * z["Routeperc"]
z.loc[:, ["Route", "Waterperc", "Snelfperc"]].groupby("Route").sum()

# group calculations percentage variables
frame3 = z.loc[:, ["Route","Waterperc","Snelfperc"]].groupby("Route").sum()
frame3

# load routes
result = pd.merge(frame1, frame2, on = "Route").merge(frame3, on = "Route")
result

# calculate route length
length = final_df.loc[:, ["Route", "length"]]
length = length.groupby("Route").mean()
length["length"] = length["length"].apply(lambda x: round(x, 2))
length

# add extra spatial variables to dataframe
spatjoin = pd.read_csv('SpatialJoinfile.txt', sep=",")
spatjoin

# prepare temp file for calculation percentage variables
spatjoin2 = pd.merge(length, spatjoin, on = "Route")
```

```
spatjoin2

# calculate percentage for spatial variabes in tempfile
spatjoin2["Ongev/len"] = spatjoin2["Ongevallen"] / spatjoin2["length"]
spatjoin2["Stop/len"] = spatjoin2["StopBordenLicht"] / spatjoin2["length"]
spatjoin2["Brug/len"] = spatjoin2["Bruggen"] / spatjoin2["length"]
spatjoin2["Misdaad/len"] = spatjoin2["Misdaadcijfers"] /
spatjoin2["length"]
spatjoin2["Ongev/len"] = spatjoin2["Ongev/len"].apply(lambda x: round(x,2))
spatjoin2["Stop/len"] = spatjoin2["Stop/len"].apply(lambda x: round(x, 2))
spatjoin2["Brug/len"] = spatjoin2["Brug/len"].apply(lambda x: round(x, 2))
spatjoin2["Misdaad/len"] = spatjoin2["Misdaad/len"].apply(lambda x:
round(x, 2))
spatjoin2

# prepare spatial variables for output
spatjoin3 = spatjoin2.loc[:, ["Route", "Ongev/len", "Stop/len", "Brug/len",
"Misdaad/len"]]
spatjoin3

# add extra non-spatial variables
DonkerlichtWeer = pd.read_csv('Donkerlicht_Weer.txt', sep=",")
DonkerlichtWeer

# add variables daylight, precipitation and name of alternative
result2 = pd.merge(result, spatjoin3, on = "Route").merge(DonkerlichtWeer,
on = "Route")
result2.insert(3, "Alternative", "Observed")
result2

# create output excel file
result2.to_excel("MergeObservedRoutes.xlsx")
```

G.4 script that adds length as spatial variable to output excel

```
# add variable length to each route alternative
import pandas as pd
import os
from pandas import ExcelWriter
from pandas import ExcelFile

# open excel to add variable to and create dataframe
df1 = pd.read_excel(
     os.path.join("MergeObservedRoutes.xlsx"),
     engine='openpyxl',)
df1

# create variable length and store value from excel file with length
length = pd.read_csv("lengthtrsafe.txt", sep=",")
length

# add value to dataframe
New = pd.merge(df1, length, on = "Route")
del New["Unnamed: 0"]
New

# output excel file
New.to_excel("MergeTrSafeRoutes_length.xlsx")
```

G.5 script that adds measure of greenery as spatial variable to output excel

```
# add green_len as spatial indicator
import pandas as pd
import numpy as np

# create dataframe
pd.set_option('display.max_column', None)
pd.set_option('display.max_rows', None)


# open excel file
import os
filenames = []
print(os.getcwd())
for f in os.listdir():
    if f.endswith(".txt"):
        filenames.append(f)

# set up dataframe
dataframes = [pd.read_csv(f, delimiter=";") for f in filenames]
tracker_df = []

# set up calculation
for df, name in zip(dataframes, filenames):
    df.insert(0, "Route", f"{name.split('.')[0]}")
    df.insert(1, "TrackerID", f"{name[:5]}")
    df.insert(2, "numberoflinks", f"{len(df)}")
    tracker_df.append(df)
final_df = pd.concat(tracker_df).reset_index(drop=True)
del final_df["Shape_Le_1"]
final_df.iloc[:, 66:-2] = final_df.iloc[:, 66:-2].convert_dtypes()
final_df.iloc[:, 66:-2] = final_df.iloc[:, 66:-2].apply(lambda x:
x.str.replace(",", "."))
final_df.iloc[:, 66:-4] = final_df.iloc[:, 66:-4].apply(lambda x:
x.astype("float").astype("int"))
final_df["Shape_Leng"] = final_df["Shape_Leng"].convert_dtypes()
final_df["Shape_Leng"] = final_df["Shape_Leng"].str.replace(",",
".").astype("float").apply(lambda x: round(x, 2))
final_df["length"] = final_df["length"].astype("float").apply(lambda x:
round(x, 2))
final_df

# give every df a unique column id
final_df["Routeperc"] = ((final_df["Shape_Leng"] / final_df["length"]) *
100).apply(lambda x: round(x, 2))
final_df

# import attributes from Fietsersbond network
pd.get_dummies(final_df, prefix="", prefix_sep="")
x = pd.get_dummies(final_df.loc[:, ["WEGNIVEAU", "WEGTYPE", "WEGDEKSRT",
"OMGEVING", "VERLICHTIN", "MAXSNELHEI", "KRP_TYPE"]])
x.insert(0, "Route", final_df["Route"])
x.insert(1, "TrackerID", final_df["TrackerID"])
x.insert(2, "numberoflinks", final_df["numberoflinks"])
x

# calculate attribute times length
x.insert(3, "length", final_df["Shape_Leng"])
```

```
x["akkers/weilanden"] = x["OMGEVING_akkers/weilanden"] * x["length"]
x["Bebouwd(veelgroen)"] = x["OMGEVING_bebouwd (veel groen)"] * x["length"]
x["Bebouwd(weiniggroen)"] = x["OMGEVING_bebouwd (weinig of geen groen)"] *
x["length"]
x["Bos"] = x["OMGEVING_bos"] * x["length"]
x["Landelijk"] = x["OMGEVING_landelijke of dorps"] * x["length"]
x["Natuur"] = x["OMGEVING_natuur (behalve bos)"] * x["length"]
x

# weigh valuations Fietsersbond
y = x.loc[:, ["Route", "akkers/weilanden", "Bebouwd(veelgroen)",
"Bebouwd(weiniggroen)", "Bos", "Landelijk",
"Natuur"]].groupby(["Route"]).sum()
y["akkers/weilanden"] = y["akkers/weilanden"] * 0.5
y["Bebouwd(veelgroen)"] = y["Bebouwd(veelgroen)"] * 0.5
y["Bebouwd(weiniggroen)"] = y["Bebouwd(weiniggroen)"] * 0.1
y["Bos"] = y["Bos"] * 1
y["Landelijk"] = y["Landelijk"] * 0.75
y["Natuur"] = y["Natuur"] * 1
y["Naturescore"] = y["akkers/weilanden"] + y["Bebouwd(veelgroen)"] +
y["Bebouwd(weiniggroen)"] + y["Bos"] + y["Landelijk"] + y["Natuur"]
y

# allocalte length to route
length = final_df.loc[:, ["Route", "length"]]
length = length.groupby("Route").mean()
length["length"] = length["length"].apply(lambda x: round(x, 2))
length

# summarize green_len per route
join = pd.merge(y, length, on = "Route").merge(frame3, on = "Route")
join["score"] = join["Naturescore"] / join["length"]
join["score"] = join["score"].apply(lambda x: round(x, 2))
join

# locate file and write
join.to_excel("GroenObserved.xlsx")
```

Appendix H. Spatial indicator appreciation

Obstruction	Value
NO DATA	0
Very few	1
Few	2
Significant	3
Much	4
Very much	5

Aesthetic	Value
Displeasing	-2
Boring	-1
Neutral	0
Scenic	1
Picturesque	2

Street lighting	Value
NO DATA	0
No light	1
Limited light	2
Well lit	3

Greenery	Value
NO DATA	0
Meadows	1
BE (much green)	2
BE (no green)	3
Forest	4
Rustic	5
Nature	6

Water	Value
Percentage	% of route

Precipitation	Value
No	0
Yes	1

Bridges	Value
Amount	Number of bridges

Daylight	Value
Dark	0
Light	1

Appendix I. Coded variables for statistical analysis

route
Key identifying the route and its alternatives

alternative
Identification of sort of alternative

green_len
Valuation of route segments based on 100% for forest and nature without forest, 75% for rural, 50% for meadow and built environment much green and 10% greenness for built environment few green divided by route length

obstruction
The mean of Likert-scale based valuation of the route segments ranging from 0 for zero to no obstruction to 5 for much obstruction

aesthetic
The mean of Likert-scale based valuation of the route segments ranging from -2 for very displeasing scenery to 2 for picturesque scenery

light
The mean of Likert-scale based valuation of the route segments ranging from 0 for no streetlights to 3 for a well-lit route

waterperc
Percentage of the route that passes a water body determined by the number of route segments with water divided by the total number of segments in the route divided by route length ranging from 0-100

bridge_len
Number of bridges divided by route length

daylight	
dark - light	0 - 1

length
Length in meters

precipitation	
No precipitation	0
Precipitation	1

sex	
Female	0
Male	1

car availability	
No	0
Yes, in consultation	1
Yes, always	2

income	
I do not know/I do not want to provide info	.
Less than € 2000	0
Between € 2000 and € 4000	1
Between € 4000 and € 6000	2
More than € 6000	3

cycling experience	
daily	0
Approximately 1 day per week	1
Approximately 2 days per week	2
Approximately 3 days per week	3
Approximately 4 days per week	4
Approximately 5 days per week	5
Approximately 6 days per week	6

household	
Single without children living at home	0
Single with children living at home	1
Living together/married without children living at home	2
Living together/married with children living at home	3
Cohabiting with other adults	4
Living at home	5

trippurpose	
Leisure (sport, recreative)	1
Utilitarian functional (work/school, utilities)	1
Utilitarian social (friends/family, other)	1
Leisure and utilitarian functional	2
Leisure and utilitarian social	2
Utilitarian functional and utilitarian social	2
Leisure, utilitarian functional and utilitarian social	3

urbanity	
rural	0
urban	1

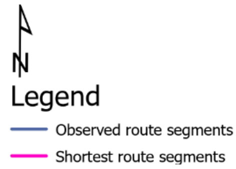
Appendix J. STATA model commands

```
*=====================================================================
* Route choice modelling bicycle use
* GIMA Green Built Environment
* Harmke Vliek, 2021
*=====================================================================

* standard folder for all data
cd "C:\Users\harmk\Documents\UU\scriptie\GIS phase\STATA"
* import
clear all
import excel env_data_Harmke.xlsx, sheet("Blad1") firstrow
save gimathesis.dta, replace

*---------------------------------------------------------------------
* Data preparation
*---------------------------------------------------------------------
use gimathesis.dta, clear

* id
egen id = group(route)
bysort id: generate gid = _n
generate choice = 1 if gid == 1
replace  choice = 0 if gid != 1
order id gid choice, first

drop if id == .

rename precipitation precip
rename cyclingexperience cycexp
rename caravailable car

generate lenkm = length/1000

destring income, replace

*---------------------------------------------------------------------
* Descriptives
*---------------------------------------------------------------------
/* just for observed */ *keep if alternative == "Observed"
tab obstruction

* compare environment characteristics per route alternative
tab alternative, summarize(lenkm)
tab alternative, summarize(green_len)
tab alternative, summarize(waterperc)
tab alternative, summarize(aesthetic)

* detect why precip and daylight do not present enough within case variance
tab precip choice
tab daylight choice

* mean per choice
tab choice, summarize(lenkm)
tab choice, summarize(green_len)

* check for correlation between variables
correlate choice lenkm waterperc aesthetic green_len bridge_len light ///
```

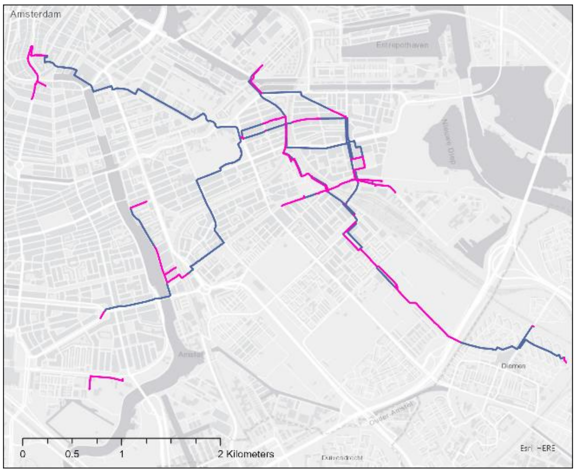
```
      obstruction precip daylight ///
      age gender income household trippurpose car cycexp

*--------------------------------------------------------------------
* Model
*--------------------------------------------------------------------
*Set choice model
cmset pid id alt

/*
Environment characteristics
*/
* effect of singular environment characteristics on route choice
probability
cmxtmixlogit choice green_len, noconstant nolog or
cmxtmixlogit choice aesthetic, noconstant nolog or
cmxtmixlogit choice waterperc, noconstant nolog or
cmxtmixlogit choice bridge_len, noconstant nolog or
cmxtmixlogit choice light, noconstant nolog or
cmxtmixlogit choice daylight, noconstant nolog or
cmxtmixlogit choice precip, noconstant nolog or
cmxtmixlogit choice obstruction, noconstant nolog or
cmxtmixlogit choice lenkm, noconstant nolog or

* effect of variables on choice probability with relative best log
likelihood
cmmixlogit choice lenkm green_len waterperc aesthetic bridge_len light ///
   , noconstant nolog or

* effect of measure of environment variable on the length of route choice
probability
cmxtmixlogit choice lenkm c.lenkm#c.green_len, noconstant nolog or
cmxtmixlogit choice lenkm c.lenkm#c.waterperc, noconstant nolog or
cmxtmixlogit choice lenkm c.lenkm#c.aesthetic, noconstant nolog or
cmmixlogit choice lenkm c.lenkm#c.green_len c.lenkm#c.waterperc ///
   c.lenkm#c.aesthetic

* effect of urbanity of the environment on greenness of route choice
probability
cmxtmixlogit choice green_len c.green_len#i.urbanity, noconstant nolog or

* effect of urbanity of the environment on waterpercentage of route choice
probability
cmxtmixlogit choice waterperc c.waterperc#i.urbanity, noconstant nolog or

* effect of urbanity of the environment on aesthetic of route choice
probability
cmxtmixlogit choice aesthetic c.aesthetic#i.urbanity, noconstant nolog or

* effect of light on green route choice
cmxtmixlogit choice c.green_len#c.light c.waterperc#c.light ///
    c.aesthetic#c.light, noconstant nolog or

/*
Personal characteristics
*/
* significant effects of personal characteristics on greenness of route
choice probability
```

```
cmxtmixlogit choice green_len c.green_len#c.age, noconstant nolog or
cmxtmixlogit choice green_len c.green_len#c.income, noconstant nolog or

* significant effects of personal characteristics on amount of water of
route choice probability
cmxtmixlogit choice waterperc c.waterperc#c.age, noconstant nolog or
cmxtmixlogit choice waterperc c.waterperc#c.gender, noconstant nolog or
cmxtmixlogit choice waterperc c.waterperc#c.income, noconstant nolog or
cmxtmixlogit choice waterperc c.waterperc#c.trippurpose, noconstant nolog
or
cmxtmixlogit choice waterperc c.waterperc#c.car, noconstant nolog or
cmxtmixlogit choice waterperc c.waterperc#c.cycexp, noconstant nolog or
cmxtmixlogit choice waterperc c.waterperc#c.household, noconstant nolog or

* significant effects of personal characteristics on measure of
environmental aesthetic of route choice probability
cmxtmixlogit choice aesthetic c.aesthetic#c.household, noconstant nolog or
```

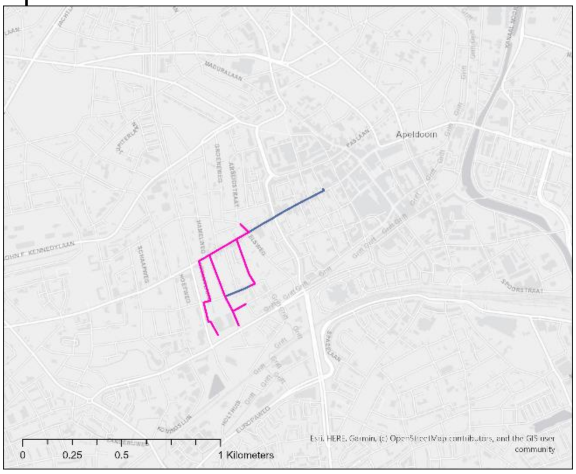
Appendix K. Shortest route segments on observed route segments



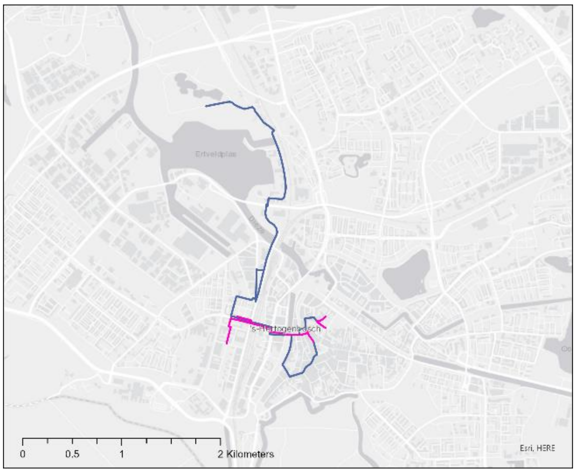
Amsterdam



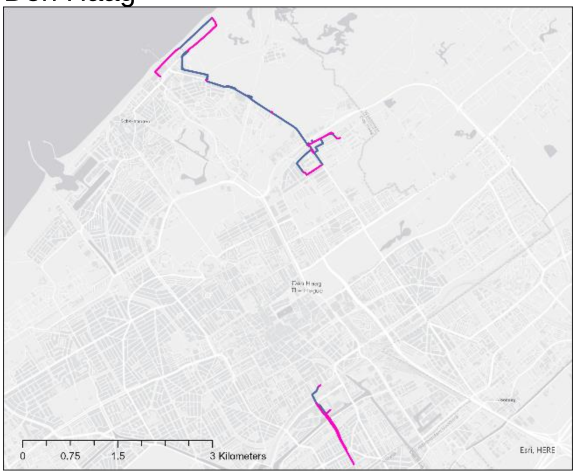
Apeldoorn



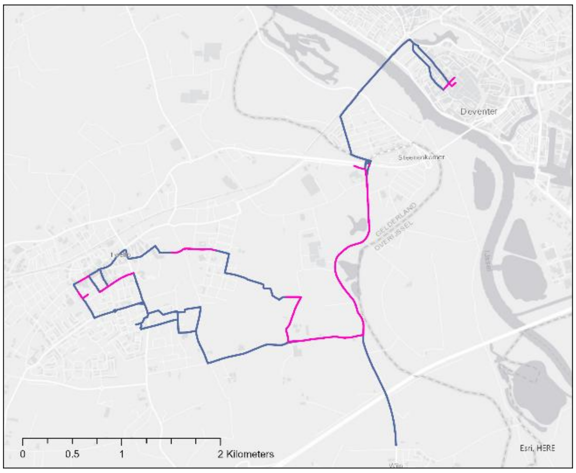
Den Bosch



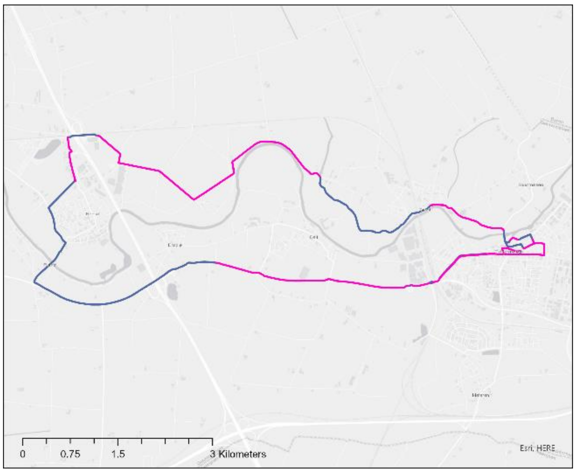
Den Haag

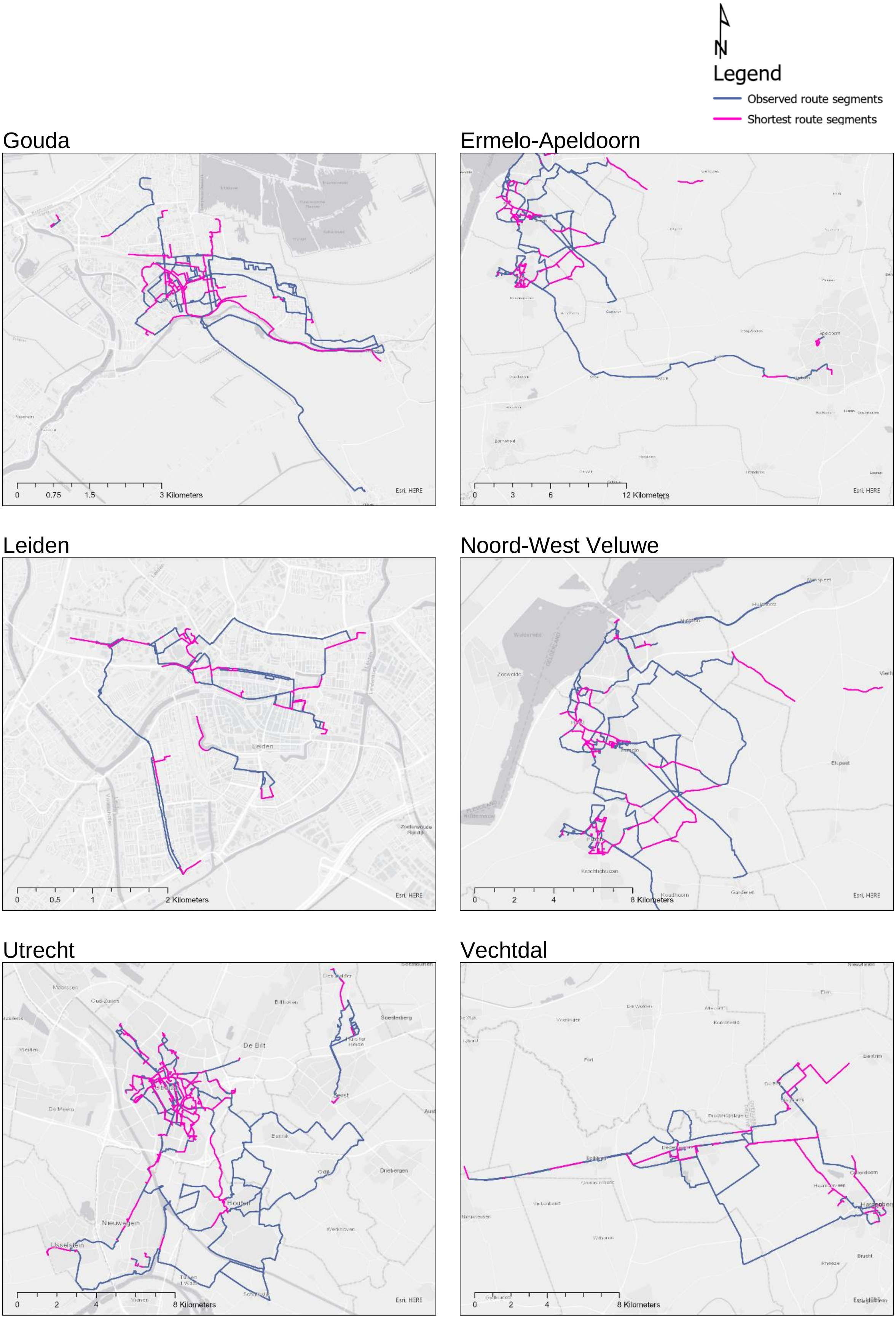


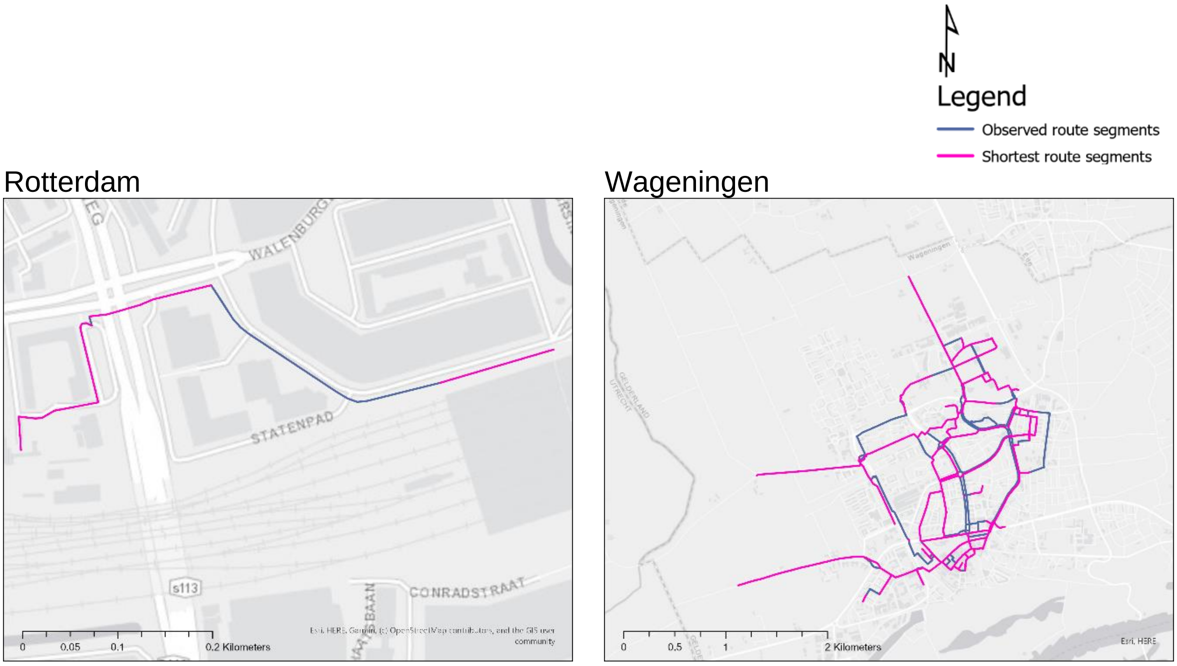
Deventer



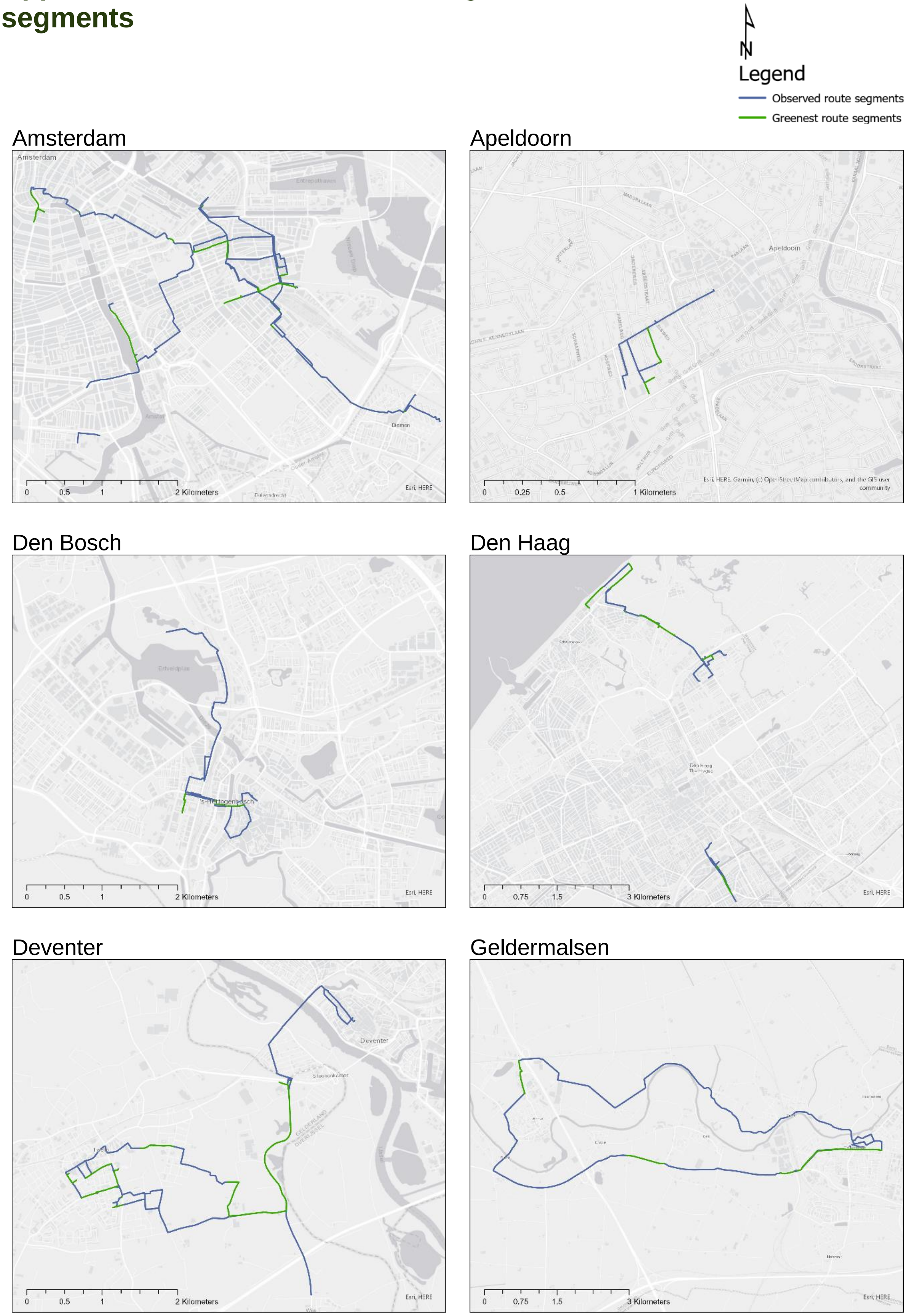
Geldermalsen




N
Legend
Observed route segments
Shortest route segments
Gouda
0 0.75 1.5 3 Kilometers
Esri, HERE
Ermelo-Apeldoorn
0 3 6 12 Kilometers
Esri, HERE
Leiden
0 0.5 1 2 Kilometers
Esri, HERE
Noord-West Veluwe
0 2 4 8 Kilometers
Esri, HERE
Utrecht
De Bilt
Nieuwegein
0 2 4 8 Kilometers
Esri, HERE
Vechtdal
0 2 4 8 Kilometers
Esri, HERE


N
Legend
Observed route segments
Shortest route segments
Rotterdam
Wageningen
WALENBURG
STATENPAD
CONRADSTRAAT
s113
0 0.05 0.1 0.2 Kilometers
0 0.5 1 2 Kilometers
Esri, HERE

Appendix L. Greenest route segments on observed route segments



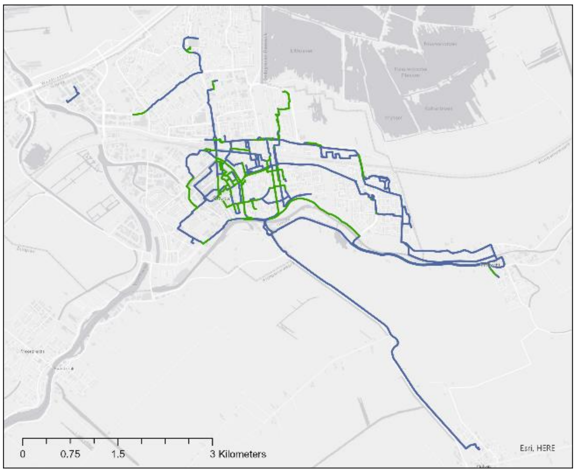
N

Legend

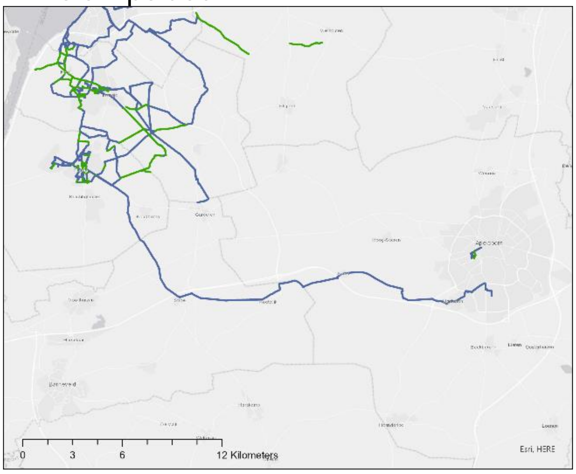
Observed route segments

Greenest route segments

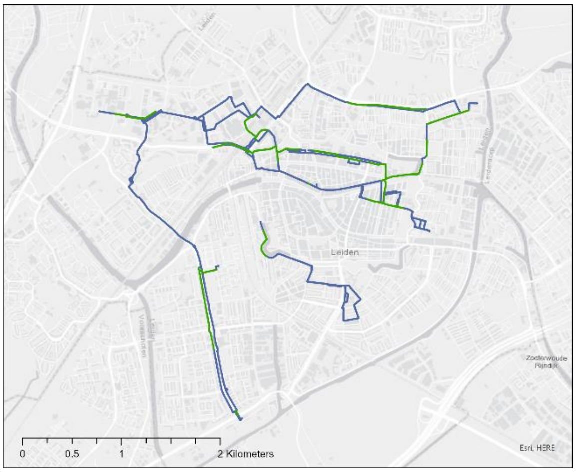
Gouda



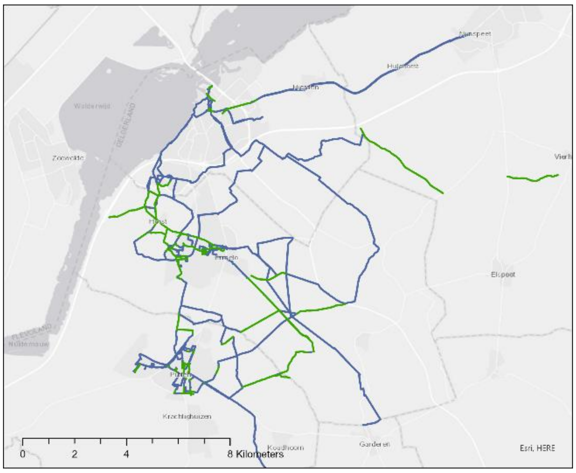
Ermelo-Apeldoorn



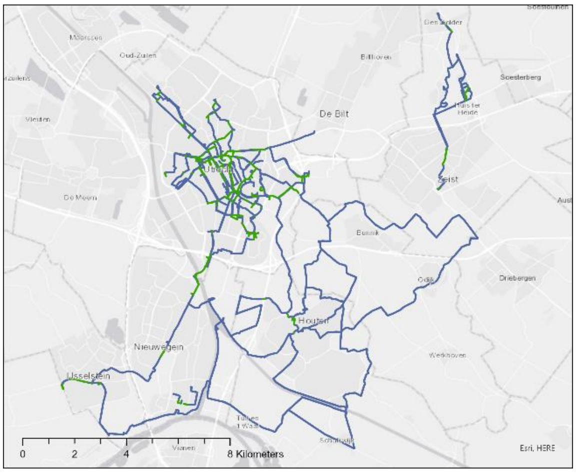
Leiden



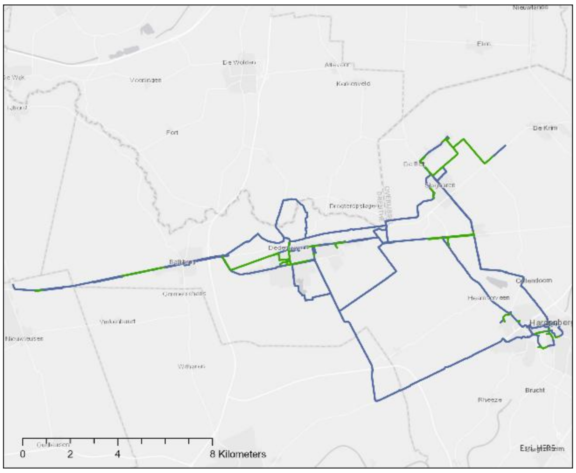
Noord-West Veluwe

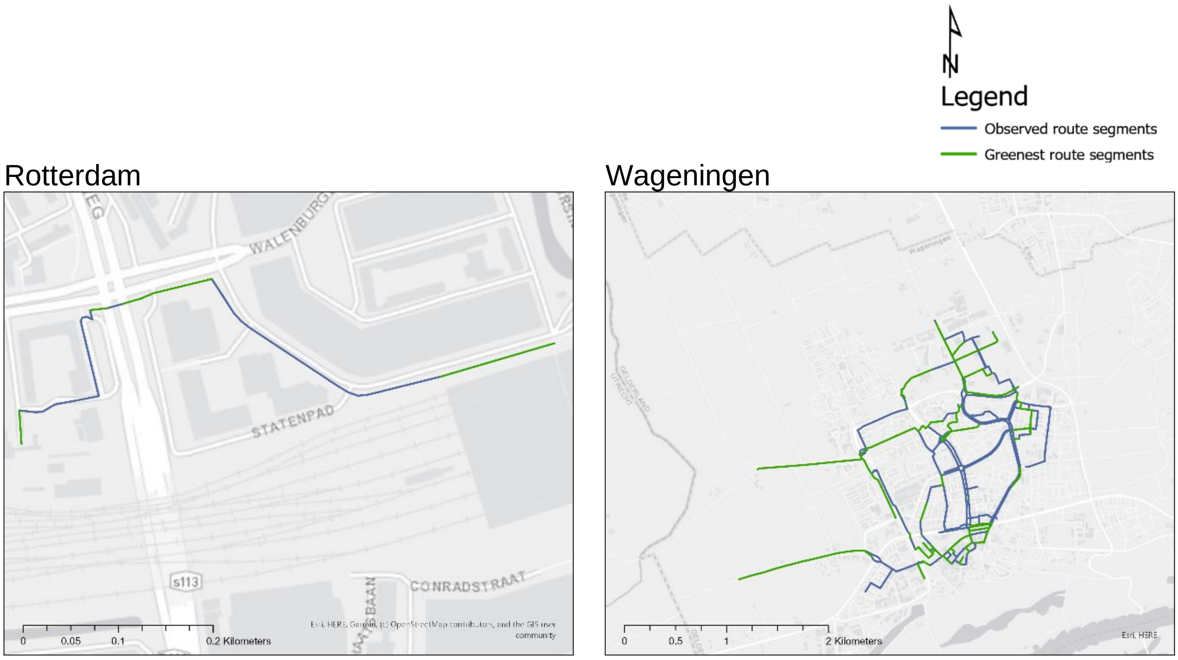


Utrecht



Vechtdal




N
Legend
Observed route segments
Greenest route segments
Rotterdam
WALENBURG
STATENPAD
CONRADSTRAAT
s113
0 0.05 0.1 0.2 Kilometers
Wageningen
0 0.5 1 2 Kilometers
Esri, HERE