Eindhoven University of Technology

MASTER

The influence of comfort aspects on route- and mode-choice decisions of cyclists in the Netherlands
an approach to improve bicycle transportation planning in practice

van Overdijk, R.P.J.

Award date:
2016

R.P.J. van Overdijk

THE INFLUENCE OF COMFORT ASPECTS ON ROUTE- AND MODE-CHOICE DECISIONS OF CYCLISTS IN THE NETHERLANDS

An approach to improve bicycle transportation planning in practice

MSc Thesis
Eindhoven University of Technology
Construction Management & Engineering

COLOPHON

Graduation thesis
In partial fulfilment of the requirements for graduation of the Master's degree Construction Management and Engineering

Name	R.P.J. (Rens) van Overdijk
TU/e ID	0743995
E-mail address	rens.vanoverdijk@live.nl

Report publication date	11th of February 2016
Graduation date	18th of February 2016
Graduation program	Construction Management and Engineering
Institute	Eindhoven University of Technology
Faculty	The Built Environment

The proposal is written in collaboration with

Eindhoven University of Technology
Den Dolech 2
5612 AZ Eindhoven

Royal HaskoningDHV
Larixplein 1
5616 VB Eindhoven

Graduation Committee

Prof. Dr. Ir. B. (Bauke) de Vries
Eindhoven University of Technology

Ir. A.W.J. (Aloys) Borgers
Eindhoven University of Technology

Dr. Ing. P.J.H.J. (Peter) van der Waerden
Eindhoven University of Technology

Ing. M.B.J. (Martin) Wouters
Royal HaskoningDHV

“Life is like riding a bicycle. To keep your balance you must keep moving.”

- ***Albert Einstein***

ACKNOWLEDGEMENTS

After six months of hard work, a lot of meetings with my graduation committee and hours of work as an intern at Royal HaskoningDHV, I am proud to finally present the official thesis to fulfill the Masters' degree of Construction Management and Engineering at the Eindhoven University of Technology. During the process of my education at the university, I started within the field of the Built Environment during the Bachelor, continued with my Master in the field of Urban Development and now (almost) graduated in the field of Urban Mobility. Before getting into the content of this report, I would first like to express my gratitude toward the people who have contributed to making this research possible.

I would like to thank Aloys Borgers and Peter van der Waerden for their very personal support and the time they have made to share their knowledge with me during the meetings and to provide feedback on my thesis. The feeling that they were always available for guidance during the research process really gave me confidence. They have provided me the guidance I needed with statistical research and choice modelling. Their involvement in the research made this graduation project a success.

Next, I would also like to thank Royal HaskoningDHV for the opportunity to graduate at the company. The enthusiasm of the team encouraged me to make the best of my graduation research possible. Especially, I would like to thank Martin Wouters for being there as my external supervisor. His knowledge of transport planning in practice, his experience with bicycle projects and his proficiency with project management was a really good help, but his enthusiasm for the research was even greater. Furthermore I would like to thank Jeroen van Ginkel for being there to share his experience with stated preference research and to provide me with recommendations to help. Then I would certainly also like to thank Bart Humblet, who made the financial contribution to the research possible. Thanks to the funding of Royal HaskoningDHV, I had the ability to spread the online survey among a panel of 790 respondents, which definitely brought the quality of the research to a higher level.

Finally, I would like to thank my friends and family for their support. Especially my parents Rob and Marja and my girlfriend Doortje for their understanding and support throughout my entire study.

I have learned a lot during these last six months of graduation. Both managing my own graduation project as being an intern at a large and successful company were a whole new experience to me. I hope the contribution of this report to bicycle research is as great as this graduation project was to me. Enjoy reading!

Rens van Overdijk
Eindhoven, 2016

SUMMARY

Increasing urbanization and population growth has led to more complexity regarding mobility in urban areas. Cities are facing higher levels of air pollution and its accessibility decreases due to traffic congestion. A more sustainable mobility solution is necessary to make the shift towards a more livable urban environment possible. The path to low-carbon mobility consists of a lot of challenges. Targeting private conventionally-fueled cars is one possible contributing solution to these challenges by encouraging the use of sustainable alternative modes of transport. The bicycle is a very suitable and sustainable alternative mode of transport.

Denmark and the Netherlands are the world leading countries in the field of bicycle usage and encouraging cycling as a mode of transport. In the Netherlands up to 26% of all trips is made by bicycle due to the high perceived safety and convenience of the bicycle as a transportation mode. On a governmental level more attention goes to developing pro-bike policies and programs which further stimulate bicycle usage. These programs do not only focus on the cities' inner mobility, but also on its accessibility by bicycle. By creating certain fast cycle routes, a connection is made between urban areas by means of a high comfort bicycle facility. Although there is a growing attention for cycling, there still exists a 'knowledge gap' when considering the effectiveness of new or improved bicycle infrastructure.

Transportation planners in practice use traffic models as a decision support tool and to simulate traffic flows. Although these models are working quite well for predicting car traffic flows, there is still a large improvement necessary in order to be able to model bicycle traffic flows. Bicycle traffic requires a more detailed infrastructural network model and a different modelling approach, since cyclists route-choice decisions are more complex and sensitive to environmental aspects. Current traffic models are based on the assumption that bicyclists always choose the shortest route, though existing literature already states that comfort aspects should also be taken into account. This research is focused on the influence of specific comfort aspects on route- and mode-choice decisions of cyclists in the Netherlands and how these relate to the influence of travel times. With this information more insight is gained in the effectiveness of bicycle infrastructural aspects on cyclists behavior and the propensity to cycle.

To investigate the influence of these aspects, a stated preference experiment was conducted. The main advantage of stated preference over revealed preference research is the ability to use choice situations that do not yet exist. Based on a comprehensive literature review, the attributes were carefully selected to be included in the choice experiment. An online survey was created and pre-tested and finally spread among an online panel of 790 respondents who are used to cycling. After data preparation, 728 respondents remained for further analyses. Within the survey, the respondents were assigned according to their previous answers to either a conventional bicycle or E-Bike, a long or short distance trip and to either a commuting or recreational purpose experiment. The analysis was divided into three parts: A route-choice model which focuses on the influence of specific comfort aspects on route-choice decisions; a route-comfort model which is based on the level of comfort the respondent attached to each route alternative; and a mode-choice model which is used to investigate the influence of route-comfort, parking facilities and travel time aspects on the mode-choice. For the route- and mode-choice model a multinomial logit model is estimated taking into account both main

and interaction effects. For the route-comfort valuation an ordinal regression was used as a first approach, though a multinomial logistic regression provided more accurate results.

In contrary to what is assumed in conventional traffic models, the bicycle facility, pavement quality and slopes on the route turned out to be of more influence on route-choice than a travel time reduction of 4 minutes. Priority intersections did not significantly influence the route-choice decisions. Significant differences were observed for a few minutes of travel time reduction on long and short distance trips. Several interactions were also found significant for different trip purposes, age groups, bicycle types and gender. The influence of a bicycle facility for instance showed a large difference between E-Bike users and standard cyclist and for different age groups.

During the route-choice experiment the respondents did also have to rate the comfort of each route alternative on a five-star scale. Both ordinal and multinomial logistic regression resulted in the same order of attribute importance. Regarding the valuation of route-comfort, pavement quality, bicycle facilities, and slopes were most influential, followed by other traffic speed, non-priority intersections, traffic lights and priority intersections.

For the mode-choice experiment, the respondents could choose between the bicycle, car and public transport as a mode of transport. The bicycle seemed to have the preference since it had the highest value for the alternative specific constant, followed by the car. Since the respondents were selected for the survey based on their bicycle usage, there existed some bias towards choosing the bicycle, which explains the high alternative specific constant value. For choosing the bicycle as a mode of transport, the availability of a (secured) parking facility had the largest impact, followed by the level of comfort of the route and a 4 minute travel time reduction on short distance trips. Hence, it can be stated that providing secure bicycle parking facilities and improving the route comfort has more effect on the propensity to cycle than providing more direct bicycle routes. Travel time reductions on longer distance trips did not significantly influence the choice for the bicycle. For the car and public transport, travel time was most influential. Most significant interaction effects were found for the alternative specific constant values. The alternative specific constants of the modes showed different values for age groups, gender, trip distances and trip purposes. Besides that, the availability of a bicycle parking facility had more impact on long distance and commuting cyclists.

Finally, a comparison of the results was made by applying the found results on an example scenario with a shorter though less comfortable route alternative and a longer though more comfortable route alternative and compare this with a conventional model calculation. The route-choice assignment which was calculated with the found results showed that the longer though more comfortable route was preferred over the shortest route, while the calculation with a conventional traffic modelling tool showed that the shortest route had the highest preference. Bicycle traffic modelling in practice requires a different approach then the current methods which are based on car traffic modelling and shortest path preferences. This research may contribute to improved bicycle traffic models by having provided insight in the utilities of more elaborate comfort aspects. This research may serve as a theoretical grounding for bicycle traffic modelling which has hitherto been missing.

SAMENVATTING

De toenemende stedelijke ontwikkeling en populatiegroei heeft geleid tot meer complexiteit op het gebied van mobiliteit in het stedelijk gebied. Steden hebben steeds meer te maken met luchtvervuiling en verslechterde bereikbaarheid van de stad door filevorming. Een duurzame mobiliteitsoplossing is nodig om de transitie naar een meer leefbare stedelijke omgeving mogelijk te maken. De weg naar duurzame mobiliteit bestaat uit veel uitdagingen. Het aanpakken van de autocultuur door het stimuleren van duurzamere alternatieve vervoersmiddelen is een mogelijke oplossing. De fiets is in dit geval een zeer geschikt en duurzaam alternatief vervoersmiddel.

Denemarken en Nederland zijn wereldwijd het voorbeeld als het gaat om fietsgebruik en het stimuleren van fietsen. In Nederland wordt zo'n 26% van alle ritten uitgevoerd met de fiets, mede door de hoge ervaren veiligheid en het gebruiksgemak van de fiets als vervoersmiddel. Op overheidsniveau wordt steeds meer aandacht geschonken aan fietsbeleid en programma's die fietsgebruik verder stimuleren. Deze programma's leggen de focus niet alleen maar op binnenstedelijke mobiliteit, maar ook op de bereikbaarheid met de fiets. Door het aanleggen van zeer comfortabele snelfietsroutes wordt een aantrekkelijke fietsverbinding gemaakt tussen steden. Ondanks de toenemende aandacht voor de fiets, bestaat er nog altijd een 'blinde vlek' als het gaat over de effectiviteit van nieuwe of verbeterde fietsverbindingen.

Verkeerskundigen in de praktijk gebruiken verkeersmodellen als een beslissings-ondersteunende tool en om verkeersstromen te simuleren. Alhoewel deze modellen aardig goed werken voor de simulatie van autoverkeer, is er voor het fietsverkeer nog veel ruimte voor verbetering. Fietsverkeer vraagt om een meer gedetailleerd infrastructureel modelnetwerk en een andere modelaanpak vanwege het feit dat fietsgedrag veel complexer is en gevoeliger is voor omgevingsfactoren. Huidige verkeersmodellen zijn veelal gebaseerd op de aanname dat fietsers altijd de kortste route kiezen, echter bewijst bestaande literatuur al dat comfort aspecten ook meegenomen moeten worden. De focus van dit onderzoek is gericht op de invloed van specifieke comfort aspecten op route- en vervoerswijze-keuzes van fietsers in Nederland en hoe deze in verhouding staan tot de invloed van reistijdverkorting. Met deze informatie wordt meer inzicht verkregen in de effectiviteit van route factoren op fietsgedrag en de keuze om te fietsen.

Om de invloed van deze factoren te onderzoeken, is een 'stated preference' experiment opgezet. Het grote voordeel van 'stated preference' ten opzichte van 'revealed preference' is de mogelijkheid om keuzesituaties voor te leggen aan de respondent die nog niet bestaan. Op basis van een zeer uitgebreid literatuuronderzoek zijn de attributen geselecteerd die mee zijn genomen in het keuze-experiment. Een online enquête is gemaakt en getest en vervolgens verspreid onder een panel van 790 respondenten die wel eens fietsen. Voor de analyses zijn 728 respondenten gebruikt. Binnen de enquête werden de respondenten op basis van hun antwoorden toegekend aan een standaard fiets of E-Bike, een lange of korte afstand rit en aan een woon-werk of recreatie ritdoeleinde. De analyse was opgedeeld in drie onderdelen: Een route-keuze model met de focus op de invloed van specifieke comfort aspecten op de route-keuzes; een route-comfort model, welke is gebaseerd op de comfort-waarderingen die de respondenten hebben toegekend aan elk route alternatief; en een vervoerswijze-keuze model, welke is gebruikt om de invloed van route-comfort, parkeervoorzieningen en reistijd

aspecten te onderzoeken op de vervoerswijze-keuzes. Voor het route-keuze en vervoerswijze-keuze model is een multinomiaal logit model geschat waarbij zowel de hoofdeffecten als de interactie effecten zijn meegenomen. Voor de route-comfort waardering is als eerste een ordinale regressie toegepast, echter leidde een multinomiale logistische regressie uiteindelijk tot meer precisie.

In tegenstelling tot wat wordt verondersteld in conventionele verkeersmodellen, is gebleken dat fietsvoorzieningen, wegdek kwaliteit en hellingen op de route van grotere invloed zijn op route-keuzes dan een reistijd verkorting van 4 minuten. Voorrangskruispunten bleken niet van significante invloed. Enkele minuten reistijd verkorting leverde grote verschillen in waardering op tussen lange en korte afstandsroutes. Significante verschillen werden ook gevonden voor verschillende doeleinden, leeftijden, fietstypes en geslacht. De aanwezigheid van een fietsvoorziening bijvoorbeeld werd verschillend ervaren door standaard fietsers en E-Bike gebruikers en verschillende leeftijdsgroepen.

Tijdens het route-keuze experiment werd de respondent gevraagd om elk route alternatief te waarderen op comfort aan de hand van een vijf-sterren schaalniveau. Ordinale en multinomiaal logistische regressie toonden beiden dezelfde orde van belang aan. Wegdek kwaliteit, fietsvoorziening en hellingen bleken van grootste invloed op het route-comfort, gevolgd door verkeerssnelheid, kruispunten zonder voorrang, verkeerslichten en voorrangskruispunten.

Voor het vervoerswijze-keuze experiment kon de respondent kiezen tussen de fiets, auto en het openbaar vervoer. De fiets bleek op voorhand de voorkeur te hebben door de hoogste alternatief specifieke constante waarde, dit is mogelijk door de selectie van respondenten op fietsgebruik. Voor de keuze voor de fiets als vervoersmiddel bleek dat een (bewaakte) fietsvoorziening de meeste invloed had, gevolgd door het route-comfort en een 4 minuten reistijdverkorting op korte afstanden. Vandaar dat kan worden geconcludeerd dat bewaakte fietsenstallingen en comfortabele fietsroutes van grotere invloed zijn op fietsgebruik dan het aanbieden van een kortere route. Op langere afstanden bleek enkele minuten reistijdverkorting niet significant. Voor de auto en het openbaar vervoer was reistijd het belangrijkst. De meeste significante interacties werden gevonden voor de alternatief specifieke constanten. Deze namen verschillende waarden aan voor leeftijdsgroepen, geslacht, afstanden en doeleinden. Daarnaast had de aanwezigheid van een fietsparkeervoorziening meer invloed op lange afstands-fietsers en woon-werk doeleinden.

Als laatste zijn de resultaten vergeleken met een berekening door het conventionele verkeersmodel. Hiervoor is een scenario gebruikt van een kortere, maar minder comfortabele route en een langere, maar comfortabelere route. De berekening met de gevonden resultaten liet zien dat de comfortabele maar toch langere route de voorkeur kreeg, terwijl de model berekening de voorkeur gaf aan de kortste route. Fietsmodellering vraagt om een andere aanpak dan de modellering van het autoverkeer waarbij wordt uitgegaan van de kortste route. Dit onderzoek kan een belangrijke bijdrage leveren aan de verbetering van verkeersmodellen door het verkregen inzicht in het 'nut' van de specifieke route-comfort aspecten. Dit onderzoek kan als theoretische onderbouwing van het verkeersmodel dienen, welke tot op de dag van vandaag nog ontbrak.

ABSTRACT

The increasing density of urban areas has led to mobility problems all over the world. Air pollution, noise and congestion are the results of unsustainable mobility. Governments focus their policies towards encouragement of bicycle usage to target private cars use. The Netherlands and Denmark are worldwide examples of stimulating the bicycle culture by providing comfortable and safe cycling facilities. Despite the large investments in improved bicycle infrastructure, there is still a lack of knowledge concerning the actual effectiveness of these improvements on route-choice and the propensity to cycle. Transportation planners in practice often base bicycle traffic flows on the assumption of shortest path preference, though existing literature proves that specific comfort aspects should also be taken into account. The traffic models which are used by transportation planners as a decision support tool, require another assignment method and better theoretical grounding. In this research the influence of comfort aspects on route- and mode-choice decisions of cyclists and how these do relate to the influence of travel time savings is investigated. A stated preference experiment was completed by 728 respondents in the Netherlands. The availability of bicycle facilities, the pavement quality and the presence of slopes on a cycling route seem to be of more influence than 4 minutes of travel time savings on the route-choice. Regarding mode-choice decisions, the experiment turned out that providing secured bicycle parking facilities and a higher route-comfort are of more influence on the propensity to cycle than providing a shorter route. Besides the utility values for these aspects, also an elaborate definition for bicycle route-comfort is found in this research. The results have finally been compared to conventional traffic model calculations. The comparison showed that taking into consideration specific route aspects leads to a different bicycle traffic assignment. This research may be seen as a contribution to the theoretical grounding and improvements of bicycle traffic models.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

1.1. Problem Definition

Increasing urbanization and population growth and their effects on the environment are major topics on both political agendas as well as in recent literature. Due to the increasing density in urban areas, cities are becoming more complex (Neirotti, *et al.*, 2014). The current situation concerning mobility in urban areas is not sustainable. Cities are facing high levels of air pollution, noise and CO_2 emissions. Private car owners are responsible for a large share of the unsustainable mobility. The increase of traffic congestion and pollution has led to a growing need for new and smart mobility solutions. Researchers state that trillions of dollars and millions of lives could be saved in the future by controlling vehicle pollution, improving public transport and shifting away from the car culture (*Climate News Network*, 2014). The European Commission has set sustainability targets to be met for 2020. One of these targets is to reduce at least 20% of the carbon emission (European Commission, 2010). The path to low-carbon mobility consists of a lot of challenges and barriers. Accenture (2014) revealed four solutions to assist cities in regulating the modal-shift form car use to alternative transport modes and conquer the challenges by: Involving public opinion; Targeting private conventionally-fueled cars; Encouraging alternative transport; and Introducing Intelligent Transport Systems (ITS). Implementing ITS functions is a top-down approach for municipalities and public involvement is a bottom-up approach where municipalities create awareness and support for the initiatives. Both these top-down and bottom-up approaches help targeting the private cars and stimulate alternative transport modes. One example of targeting private conventionally-fueled cars is creating more car-free zones in urban areas. An example of stimulating alternative transportation is encouraging bicycle usage. The bicycle is a very suitable and sustainable alternative transportation mode (Accenture, 2014).

Amsterdam and Copenhagen are world leading cities in the field of bicycle usage, where the bicycle is the most preferred mode of transport and where the share of segregated bike lanes is the highest (Accenture, 2014). Overall, The Netherlands can be considered as the world's leading cycling country, accounting for a modal share up to 26% of all trips being cycling (Carse, *et al.*, 2013). Together with Denmark and Germany, The Netherlands is considered as a good example where cycling is a safe, convenient and a practical mode of transport (Pucher & Buehler, 2008). Pucher and Buehler (2008) describe that the high level of bicycle usage in The Netherlands is a result of the provided separate cycling facilities along busy roads and intersections, as well as the traffic calming and car-free zones in residential neighborhoods. The availability of bicycle parking facilities, and the level of integration with public transport are other important aspects which stimulate the bicycle usage. The Netherlands is seen as a country where bicycle usage is supported by public enthusiasm. Besides the inconvenience and costs of car driving and parking in Dutch cities, which stimulates alternative modes of transport e.g. cycling, there are also pro-bike policies and programs in the Netherlands which stimulate bicycle usage as a transportation mode. 'Fiets FileVrij' as part of 'Fileproof' and 'Beter Benutten' are examples of programs initiated by the Dutch government. The focus of 'Fiets FileVrij' which started in 2006 was to reduce traffic congestion by increasing the number of bicycle commuters. The plan was initiated for commuters who live at most 15 km away from their work. By creating so called fast cycle routes or cycle highways, the city's accessibility for bicycles is being improved. 'Beter Benutten' started in 2011 and focuses also on increasing the accessibility of infrastructural bottlenecks. The program resulted in a significant increase of bicycle commuters who avoid traffic congestion during rush hours (*Platform Beter Benutten*, 2014).

In The Netherlands, 61% of the population lives within 15 km distance off their work. Only 25% of this population uses the bicycle as a transportation mode to their working destination of which 50% cycles till 5 km distance, 25% till 10 km, 10% till 15 km and 15% cycles 15km or more (*VogelvrijeFietser*, 2014). Fast cycle routes have great potential to improve the amount of cyclists on longer distance trips. The above mentioned governmental programs have already resulted in higher bicycle usage by improving the bicycle facilities and creating fast cycle routes. In 2013, the Dutch Cyclists' Union (Fietsersbond) together with the Dutch Minister of Infrastructure and Environment agreed upon a plan to expand the Dutch bicycle infrastructure network with 675 km of fast cycle routes within the year 2025 (*Volkskrant*, 2013). These fast cycle routes will create or improve primary connections between cities and will consist of high safety and comfort measures, better facilities and road signing, and priority on intersections.

The growing amount of E-Bikes and Speed Pedelecs in combination with the governmental or municipal interventions and policies have a positive effect on the modal shift from car use to bicycle use. However, information about the effectiveness of these policies and interventions is still very limited (Scheepers et al., 2014). Besides the trip characteristics, personal; social; and attitudinal aspects are also very important when looking for effective interventions (St-Louis, *et al.*, 2014). The level of satisfaction for a transport mode influences a person's choice behavior. Thomas, Walker and Musselwhite (2014) found that a behavior change and willingness to change the transportation mode is besides the level of satisfaction also dependent on the perceived autonomy with the current mode. There is a certain fear for all users to lose control and autonomy when switching transportation modes. The importance of autonomy to current users must be taken into account when considering interventions. Most of the existing literature focuses on commuting cyclists, though there is also a recreational function of bicycle usage. Piatkowski and Marshall (2015) emphasize that when considering a certain group and intervention for modal change, there is an important distinction to be made between socio-demographic and built environment factors, but also between the decision to start commuting by bicycle and the decision to increase the frequency of bicycling to work. People who never cycle will probably have a higher feeling for autonomy for their current transport mode and it will therefore be harder to convince them of behavior change.

Current literature emphasizes the importance of future research into the understanding of social factors relating to cyclists' attitudes and the influence of their environment on mode-choice and satisfaction (St-Louis *et al*., 2014). Getting more insight into people's route-choice and mode-choice behavior will lead to better understanding of the demand and requirements of bicycle infrastructure. The outcomes of such a research should be used and based on applicability in bicycle infrastructure panning tools. There exists a growing attractiveness of cycling with an increasing mode share as a result, though there is still only little scientific attention. The traffic flow simulation models of transport planners are working quite well for car traffic, but cycling consists of more complex behavioral dimensions. Cyclists are more sensitive to the environment and hence more environmental aspects should be implemented in the modelling tools. There is still a lack of a grounded theory on cyclists behavior and models to describe this behavior. Current traffic models' focus is on car traffic flow simulation techniques, though bicycle traffic simulation asks for a different approach.

1.2. Research Question and Objective

Earlier research mentioned that measures to stimulate active transport still ask for more insight into cyclist's behavior and effectiveness of interventions (Scheepers et al., 2014). More knowledge on the topic is required in order to plan effective interventions and policy changes. As mentioned in the previous section, there are multiple aspects which influence road users to use the bicycle as a transport mode. One important aspect, which might influence the mode-choice is the perceived safety of the bicycle in traffic (Chataway, *et al.*, 2014). Van Der Waerden, Borgers and Timmermans (2006) make a distinction between bicycle safety into social safety and traffic safety. This safety aspect has an indirect connection to the perceived level of comfort of a bicycle path and thereby influences the attractiveness to use the bicycle in a certain way. Rybarczyk and Wu (2010) state that increasing the number of bicycle facilities does not directly lead to more bicycle usage or less risks in traffic. Both demand and supply have to be taken into account when planning new or improving existing bicycle facilities. Since there is an overlap in the definition of comfort and safety, the research will further elaborate on comfort aspects in specific.

Van Der Waerden, Borgers and Timmermans (2006) mention the complications of bicycle infrastructure planning and the lack of insight and concern for more specific aspects. Current planning tools for bicycle infrastructure prioritize the focus on capacity of bicycle routes and functionality, i.e. straight connections. However professionals in the field state the importance of travel times and travel time savings when using the bicycle, only few researchers have evaluated the importance of cycling aspects (Björklund & Mortazavi, 2013). Besides the importance of safety and comfort aspects, Papinski, Scott, and Doherty (2009) found reducing travel times to be the most preferred aspect of bicycle route-choice, followed by reduced number of stops, avoid congestion and maximize route directness. Research on the valuation of comfort aspects and travel time savings by cyclists might lead to better infrastructure planning when applied correctly in the current traffic modelling tools (Rybarczyk & Wu, 2010). For this endeavor to improve the position of the bicycle in current traffic modelling tools by investigating the influence of route- and mode-choice aspects, the following research question is composed:

"What is the influence of comfort aspects in comparison to travel time savings on route- and mode-choice decisions of cyclists, and how can these insights improve current traffic modelling tools?"

In order to be able to answer the above stated question, the following sub-questions are defined:

- *"What are the comfort aspects in bicycle infrastructure according to current literature?"*

- *"Which (other) factors influence the route-choice behavior of cyclists?"*

- *“Which (other) factors influence the transportation mode-choice?”*

- *“What is the actual valuation of comfort aspects in bicycle infrastructure in comparison to travel times, regarding route-and mode-choice decisions?”*

- *“What is the current practice of transport modelling?”*

- *“How can the results be implemented in current traffic models and be useful for transport planning in practice?”*

The objective of this research is to find the valuation of comfort aspects in bicycle infrastructure and how these are evaluated against travel time savings. Since traffic models which are used for infrastructure planning are based on route directness and route capacity, new insights in valuation of certain aspects (i.e. the demand side) might lead to improved effectiveness of elaborated bicycle infrastructure (i.e. the supply side). Important here, is that the focus of the research is on the route-choice decisions of road users who are considering using the car or bicycle and feel less commitment to only one of these transportation modes.

1.3. Research Design

Research concerning route-choice behavior and aspects which influence a person’s route-choice have been a topic in existing literature for quite a long time already (Bovy & Stern, 1990). The focus of the researches is mainly on individual’s decision-making processes regarding the choice of destinations; modes; departure times; and routes. The focus on bicycle usage as a transportation mode however, is still relatively new. Chapter 2 of this report consists of a literature review to answer the first, second, third and fifth sub-questions defined in the previous section. A clear overview of existing literature, previous outcomes of researches and topics which are already covered in current literature is provided and an exemplification of how transport planning in practice is done is made. The literature review forms a strong basis for future research and provides the most important attributes concerning bicyclists’ attitudes towards comfort, regarding route-choice and mode-choice behavior.

The aspects as a result of the literature review concerning comfort together with other influencing aspects (e.g. social aspects, environmental aspects) are used to design a research model for the fourth sub-question of section 1.2. Chapter 3 of this report focuses on the research approach. A common used approach to model choice behavior in the transportation field is discrete choice analysis (Ben-Akiva & Lerman, 1985). Over the last years, this method has been developed to a suitable approach for modeling demand and traveler’s behavior. According to Bovy & Stern (1990) a choice model is an operational form of a choice theory. It can be used to identify which variables contribute in a significant way to observed behavior and to determine the relationship between these variables and the observed behavior. A choice model also makes it possible to estimate behavioral parameters such as the value of time, comfort and safety. These parameters can be used in the traffic models to predict behavior in certain situations. The attributes from the literature review and the insight in transportation planning form the right aspects and factors to be covered by the choice set. The respondents will make a choice based on these choice sets, which allows to estimate the utilities of these aspects. The research is divided into separate experiments in order to be able to find the valuations for both route-and mode-choice aspects without creating an overly complex research model. The separate comfort aspects and travel time are used in a route-choice experiment which forms the first model. These route alternatives are rated with a comfort level by the respondents. The second model allows to aggregate the separate comfort aspects to only one comfort attribute based on the comfort ratings of the respondents. A third model uses the aggregated comfort attribute in combination with more mode-specific attributes to find the mode-choice attributes' importance.

When the actual valuation for the defined aspects is found, the results can be implemented in current traffic models. Traffic models are used to predict and simulate routes and route-choices of road users. The insight gained from the research model could be very useful for more effective bicycle route planning. Adding more environmental aspects such as route-comfort makes the traffic models more accurate in predicting route-choice decisions and more importantly, allows to explain why certain routes are preferred over others. An example case will be used to compare the trip assignment of the traffic modelling tools to the trip assignment according to the found results.

2. LITERATURE REVIEW

2.1. Introduction

In the past recent years, there has been an increase in interest for bicyclists' behavior regarding mode-and route-choices. Bicycle usage as a specific sustainable mode of transport has received more attention in recent literature. As a strong knowledge basis for this research as well as for future research, this chapter provides a review of the current literature in the field of cyclists' behavior. Huisman and Hengeveld (2014) explain the basic elements of traffic and transportation science using a systems diagram. Figure 1 shows this diagram which exemplifies three market segments: 'The trip market'; 'The transportation market'; and 'The traffic market'. The trip market considers the reason to move from one to another location, i.e. the purpose of the trip. The purpose of a trip is based on the activity locations, time planning and the perception of both objective and subjective characteristics. Sequent after the trip purpose is the decision of which transportation mode is used. This is translated by the transportation market consisting of the demand and supply of transportation modes, services and perceptions. After that, the decision to take a specific route is dependent on the traffic market. This market segment is based on the demand and supply of infrastructure and its attributes.

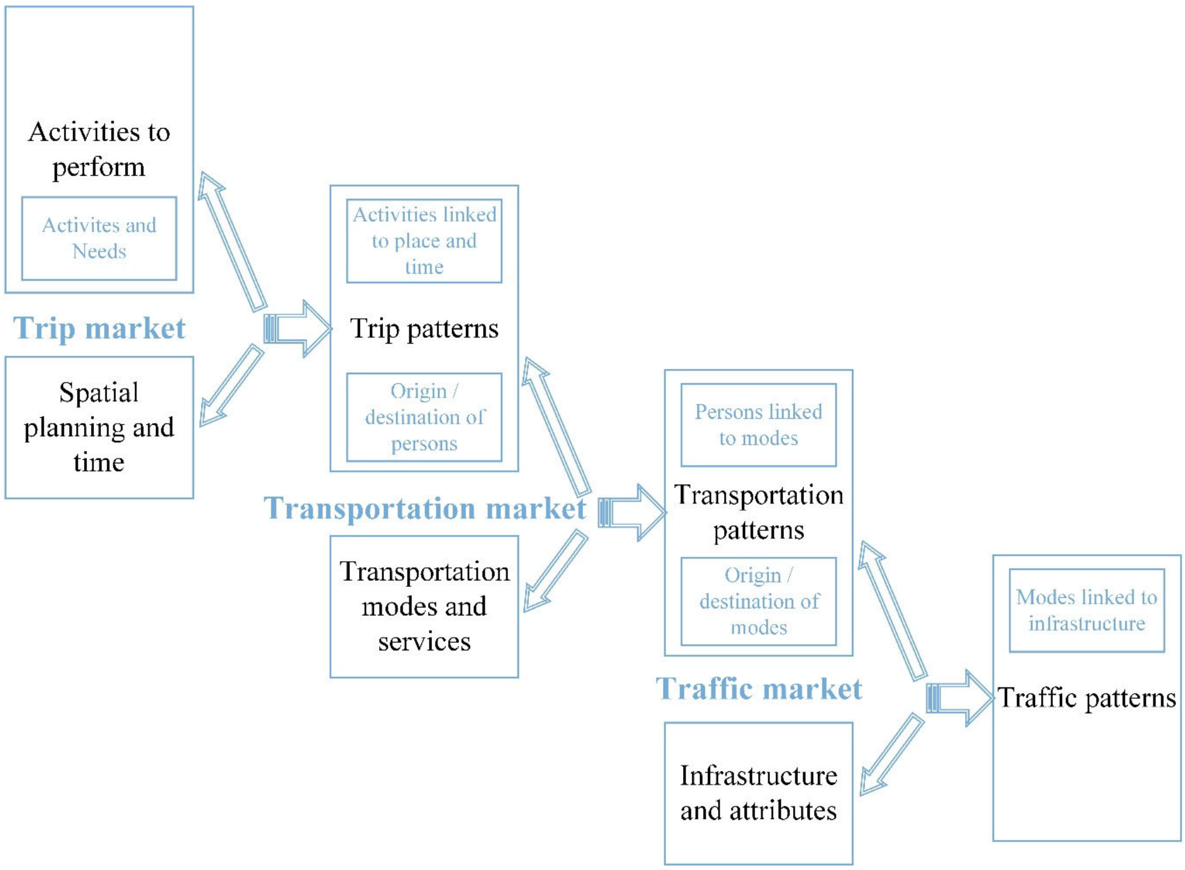


Figure 1: Systems diagram of traffic and transportation science (Van de Riet & Egeter, 1998, p. 7)

Many different studies cover a broad variety of influencing attributes or parameters which are favored by cyclists (Beheshtitabar, Aguilar Ríos, König-Hollerwöger, Svatý, & Rydergren, 2014). The valuations of these attributes are very suitable for generating functions to predict route-choices for cyclists and the modal shift from car to bicycle. Since the purpose of this research is to eventually compare and adapt these valuations of attributes in current traffic models, part of this chapter also focuses on the current practice of transportation planning and the models which are available. First, relevant studies concerning aspects which influence mode-choice behavior are reviewed, thereafter the studies concerning route-choice behavior are reviewed and finally an overview of transportation planning is given followed by a general conclusion of the findings in the literature review.

2.2. Aspects Influencing Transportation Mode-Choice Behavior

Bicycling is besides walking the most understudied mode of transport. Behavioral aspects are hard to understand and complex to study, hence there is a large research gap in bicycle related research (Krizek, Handy, & Forsyth, 2009). People's individual transportation mode-choices do not only have a strong influence on the transport system, but also on the environment and public health. People need to be willing and able to change their way of transportation in order to make the modal shift happen. Schneider (2013) describes five important factors to promote active transport: Awareness and availability; Basic safety and security; Convenience and costs; Enjoyment; and Habit. It is being emphasized that all steps should be considered in order to make the routine automobile travel shift to other modes. Majumdar and Mitra (2013) define three categories of attributes: 'User related'; 'Route and link related'; and 'Journey related', St-Louis et al. (2014) only define two types of attributes: 'Internal' and 'External' and Huisman and Hengeveld (2014) define that bike-use is being influenced by five types of factors i.e. 'Physical factors'; 'Social cultural factors'; 'Demographic factors'; 'Spatial economic factors'; and 'Traffic and transport factors'. In many researches available, social and demographic factors are merged into socio-demographic attributes. Huisman and Hengeveld (2014) however, state a major difference i.e. that the demographic attributes are based on facts which cannot be affected easily and social cultural attributes are based on personal factors and perceptions which, in contrary to the latter, can be affected by e.g. policy measures, urban planning or media attention. Since this distinction and separation of attributes suggested by Huisman and Hengeveld (2014) gives more insight for policy makers and transportation planners for instance, the same structuring is used for this chapter.

Van Boggelen and Hengeveld (2010) mention certain 'push' and 'pull' strategies to encourage the shift from car use to bicycle usage. Push measures e.g. new parking policies for cars and taxes on driven distances seem to be more effective than pull measures e.g. infrastructure improvements. Wardman, Tight and Page (2007) found that only providing new infrastructure improvements did not result in much more cycle commuting. However, stimulating the modal shift from car to bicycle for commuting purpose by a daily payment as an incentive did turn out to be very effective. However the modal shift tends to provide lots of benefits, Schepers and Heinen (2013) found no decrease in fatal traffic accidents while exploring an increase in modal shift from car to bike use. More insight into the aspects which influence the modal-shift leads to better insight in which measures to take, which policy interventions to implement or which facilities to design. The latter is important for transportation planners in order to make fast cycle routes, for instance, more effective as in more encouraging for people to take the bicycle as a transport mode.

2.2.1. *Trip purpose*

As figure 1 already exemplified, the purpose of the trip has a strong influence on people's transportation mode decision. Several researches investigate different trip purposes as being influential for mode-choice decisions (Scheepers et al., 2013; Börjesson & Eliasson, 2012; Carse et al., 2013; and Cervero & Duncan, 2003). These trip purposes are mainly described as: *'Shopping'; 'Commuting'; 'Taking or bringing persons';* and *'Leisure'*. Huisman and Hengeveld (2014) describe several factors and circumstances which influence a trip purpose. Weather conditions and season can lead to cancellations of certain activities or could create new activities to be performed. Demographic aspects such as religion, employment, education and age lead to different performed activities at different locations. The direction of the trips is mainly dependent on the location of facilities. Besides that, start and end times of activities e.g. working times and school times play an important role in travel patterns. Finally, there are certain constraints which preclude people to take part in an activity (for instance not owning a vehicle or bad weather conditions).

Spotswood, Chatterton and Tapp (2015) combine bicycle usage and trip purposes by distinguishing five different groups of cyclists: Non-cyclists, Lapsed cyclists (i.e. people who may have cycled as a child and do know the benefits, though are not willing to take it up again.), Occasional cyclists (i.e. leisure cyclists who cycle once in a month or less), Regular sports cyclists (i.e. regular leisure cyclists, no utility purpose), and Utility cyclists (i.e. people who cycle to work more than using their car). A strong attitudinal difference towards cycling for leisure and commuting cycling was observed, confirming trip purpose as an important factor regarding mode-choice decisions. People who cycle once in a while but doubt the use for commuting purpose should be encouraged or enticed to cycle more, people who are new to cycling but are willing to increase their bike use should be supported or rewarded and the utility cyclists who always cycle should perform as an ambassador and promote cycling amongst others in order to further increase bicycle usage. Although the majority of people does not contemplate cycling as a mode of transport, there is a group of people which could be persuaded by taking the right measures and focusing on the right factors which are influential (Gatersleben & Appleton, 2007).

2.2.2. *Demographic factors*

Almost all researches considering transportation mode-choice behavior, introduce socio-demographic (i.e. personal, user related, or internal) attributes to be investigated (e.g. Heinen & Chatterjee, 2015; Majumdar & Mitra, 2013; St-Louis et al., 2014; Piatkowski & Marshall, 2015; Bernhoft & Carstensen, 2008; and Cui, Mishra, & Welch, 2014). As mentioned before, in this research a distinction is perceived between social cultural and demographic factors. The comprehensive though basic demographic attributes which were found influential in earlier research are: *'Gender'*; *'Ethnicity'*; *'Age'*; *'Education level'*; *'Household composition'*; *'Economic status'*; *'Employment'*; *'Settlement type'*; *'Housing type'*; *'Housing tenure'*; *'Income'*; and *'Social-economic status'*. Krizek, Johnson and Tilahun (2005) found that cycling rates regarding gender differ per trip purpose. Women seem to be cycling more for leisure purpose, where men cycle more for commuting purpose (Beecham & Wood, 2014; and Krizek, et al., 2005). Carse et al. (2013) also include *'Health'* factors such as *'Body Mass Index (BMI)';* '*Physical Health Summary (PCS-8)*'; and *'Mental Health Summary (MCS-8)'.* These factors provide the necessary insight and background information about travelers and their decisions.

2.2.3. Social cultural factors

Social cultural factors are non-fact based attributes which can be affected or influenced by surroundings, media attention and several other incentives. These attributes are more ‘personal’ and consist of the *‘Attitudes’* and *‘Perceptions’*. St-Louis et al. (2014) investigated commuter satisfaction comparing different transport modes. Besides demographic factors such as age and gender also *‘Overall life satisfaction’* as a social cultural factor was investigated. Since *‘Religion’* can also be seen as a belief or life philosophy, it is also considered as a social cultural factor. However many researches consider demographic attributes, only few of them elaborate on perception based social cultural attributes (Majumdar & Mitra, 2013; St-Louis et al., 2014; and Piatkowski & Marshall, 2015). Majumdar and Mitra (2013) found psychological factors and *‘Perception of travel times’* and *‘Travel time flexibility’* as the third most important attributes. Cervero & Duncan (2003) mention certain deterrents which tend to impede bicycle usage. These constraints are mainly based on perceived comfort and safety and will be further explained in section 2.2.7. of this chapter.

Gössling (2013) claims that measures to foster cycling are often implemented without a strategic focus or a good understanding of bicycle cultures. ‘Market-based measures’ and ‘soft policy measures’ are two examples which are implemented by the municipality of Copenhagen and which have contributed to the bicycle usage increase. Pucher and Buehler (2008) mention and emphasize the leading position regarding bicycle share of the Netherlands, Denmark and Germany and the unsafe and inconvenient bicycle facilities and conditions in other countries such as The United Kingdom and The United States. They suggest a relationship between safety, perceived safety and bicycle promotion, since the decrease in fatality rates is followed by an increase in bicycle use. Here again, a good habit towards bicycle usage in The Netherlands is observed. *‘Traffic education and training’* at an early age and *‘Traffic laws and regulations’* have led to this habit and positive attitude towards cycling. Public policy has a crucial role in supporting bicycle encouragement (Pucher, Dill, & Handy, 2010). As already mentioned in section 2.2.1., different types of cyclists can be encouraged to change their habits and attitudes towards different modes of transport through social cultural incentives.

2.2.4. Spatial economic factors

Some literature articles focus on environmental aspects. Environmental aspects can also be separated into different factors i.e.: ‘Physical factors’; ‘Spatial economic factors’; and ‘Traffic and transportation factors’. Spatial economic factors can be considered as an expansion of the demographic attributes with *‘Trip origins’* and *‘Trip destinations’*, thus describe where people come from and travel to and at which *‘Time of the day or night’.* Cui, Mishra and Welch (2014) found a positive correlation between bicycle ridership, demographic data and socio-economic factors (e.g. *‘Population density’*; *‘Household density’*; and *‘School enrollment density’*) in the USA. A higher density resulted in higher amounts of bicycle usage, depending on the urban typology and land use. This seems to be location dependent, since in The Netherlands, higher bicycle usage ratios are observed in rural areas with lower densities than in the urban area (Huisman & Hengeveld, 2014). Scheepers et al. (2013) furthermore mention *‘Neighborhood typology’* as an influential attribute. Haybatollahi, Czepkiewicz, Laatikainen and Kyttä, (2015) found a relation between neighborhood characteristics and the level of motorized commuting.

Cervero and Duncan (2003) created a model to predict whether a trip will be made by bicycle, where they have also included specific spatial economic characteristics. These characteristics are: *'Employment accessibility'*; *'Retail/Service'*; and *'Land-use diversity'* where a distinction is made between origin and destination for the last two attributes. One of the outcomes was that the design and land-use as part of the built environment characteristics had a larger impact at the origin of a trip (i.e. the residential end) than at the destination of the trip influencing the decision to take the bicycle as a mode. Hence, density of services and facilities e.g. schools, offices and shops influence mode choice behavior as well. The amount of facilities in the surrounding area can be changed. Therefore, spatial economic factors are considered as factors which can be affected by governmental interventions and spatial planners. Winters, Brauer, Setton and Teschke (2010) provide a comprehensive study of the effect of built environment factors on healthy travel behavior. The characteristics of spatial zones seemed to be very important to consider. The presence of commercial neighborhoods, more education, industrial land and higher diversity of land-uses result in higher amounts of bicycle usage.

2.2.5. Physical factors

Physical factors are environmental factors which are hard or unable to be affected. Scheepers et al. (2013) and St-Louis et al. (2014) included *'Season'* as one physical attribute. Majumdar and Mitra (2013) more specifically added *'Weather condition'* as an attribute. Regarding bicycle usage, sun/rain ratios and wind speeds are of major importance, though its perceived importance also depends on the trip purpose. Hardly any research considers the effectiveness of measures which lessen the weather's negative effects on bicycle usage (Heinen, van Wee, & Maat, 2010). Physical factors do also consist of environmental topology and natural barriers, such as mountains (Huisman & Hengeveld, 2014).

2.2.6. Traffic and transportation factors

The final attributes belong to traffic and transportation factors. These affect to a large extent the mode- and route-choice decisions and consider e.g.: *'Mobility difficulties'*; *'Driving license possession'*; *'Car ownership'*; *'Having a public transport pass'*; and *'Bicycle ownership'*. Knowing the origin and destination of a trip allows to calculate the *'Trip distance'* and possibly the *'Trip costs'.* The perceived convenience of a transportation mode is also part of traffic and transportation factors. Heinen, van Wee and Maat (2010) mention the importance of including *'Cycling frequency'*. St-Louis et al. (2014) also consider *'Travel preference'*; and *'Mode preference'* as aspects and state that bicyclists are the most satisfied mode-users. They concluded that, although trip characteristics did not have a significant influence on car drivers' satisfaction, they did have a certain influence on bicyclists' mode satisfaction.

Heinen, Maat, and van Wee (2011) state that the decision to cycle to work is mainly based on the direct benefit of the trip, based on the convenience, health benefits, etc. They furthermore state that a distinction exists in the attitude towards cycling for longer and shorter distance trips. Short distance trip mode choices seem to be more easily affected by others than longer distance trips. *'Trip costs'* are less relevant for cycling since cycling is relatively cheap, though the comparison to the costs of other modes makes it interesting. *'Experience with the current transportation mode'* also influences the use of it. Gatersleben and Uzzell (2007) concluded that car drivers experience the most stress, where cyclists and pedestrians experience the most relaxing journeys.

Majumdar and Mitra (2013) describe traffic and transportation factors as 'route and link related' and 'journey related factors'. Route and link related attributes are: *'Route topography'*; *'Congestion'*; and *'Parking'*. Journey related attributes consider: *'Safety'*; and *'Security'.* One of the outcomes was that route topography was the most important attribute. *'Infrastructural barriers'* and *'Public transport accessibility'* also play an important role in bicycle usage. Well maintained and operating public transport services have a negative influence on bicycle usage, though could however increase the use of the bike-transit combination when bike parking facilities are provided (Huisman & Hengeveld, 2014).

2.2.7. Comfort aspects

Many researches mention comfort and safety as being influential on mode-choice decisions, without further elaborating the definition of comfort and safety. Attitudes towards bicycle usage are basically influenced by the perception of convenience, comfort and safety. St-Louis et al. (2014) investigate the travel and mode preferences of the respondents, though a reason behind the preference is missing. Piatkowski and Marshall (2015) based their selection of attributes on previous literature consisting of 'Socio-demographic'; 'Built environment'; and 'Attitude and perception' factors. The attitudinal and perception factors were the most striking factors in bicycle commuting according to the research. A distinction was made into 'safety and infrastructure' factors i.e. *'Number of bike lanes'*; *'Number of intersections between bike lanes and paths'*; *'Perception of road safety'*; *'Street conditions'*; and *'Lighting on bicycle facilities at night'*; 'security and comfort' factors i.e. *'Bicycle storage availability at work'*; *'Security perception towards theft and vandalism'*; *'Quality of the bike'*; *'Accessibility of a bike on transit'*; *'Amount of cargo to carry'*; and *'Attitude towards an active mode of transport to work'*; 'relative convenience' factors i.e. *'Attitude towards travel time increase'*; *'Perceived convenience of current and other travel-modes'*; and *'Route topography'*. If there are too many height differences on the route or when infrastructural barriers such as bridges or tunnels require longer distances to be made by bicycle, it also negatively influences bicycle use (Parkin, Ryley, & Jones, 2007). Infrastructural network adequacy requires secure bike storage and parking facilities, charging stations for e-bikes etc. Vanoutrive et al. (2009) analyzed the factors behind cycling to work for larger firms. They found that the number of available bicycle facilities did not necessarily lead to higher bicycle usage rates. This was due to the fact that large firms were often located on industrial sites outside the agglomerations and did therefore have more space to implement bicycle facilities. Although the facilities were available, certain trip characteristics such as destination accessibility became more important in the decision to cycle to work or not. Dill and Voros (2006) found that the perception of availability of cycle lanes and street connectivity led to the desire to cycle more. Schepers, Hagenzieker, Methorst, Van Wee and Wegman (2014) mention travel behavior is based on the needs, opportunities and abilities. Perceived safety is considered as a strong travel deterrent.

Pucher and Buehler (2008) summarize several implementation options to make cycling more safe and more convenient/comfortable: *'Extensive systems of separate cycling facilities'* (e.g. well maintained, fully integrated paths, lanes and special bike streets in cities; fully coordinated system of color-coded directional signs for bicyclists; off-street short-cuts i.e.

mid-block connections and passages through dead-ends for cars.); *'Intersection modifications and priority traffic signals'* (e.g. advance green lights for cyclists at most intersections; advanced cyclist waiting positions ahead of cars; cyclists short-cuts to make right-hand turns before intersections and exemption from red traffic signals at T-intersections to increase speed and safety; change of color of bike paths near intersections; synchronized traffic signals according to cyclists' speed assuring consecutive green lights (green wave); bollards with flashing lights along bike routes signal cyclists the right speed to reach the next intersection at a green light.); *'Traffic calming'* (e.g. Assigning speed limits for cars in neighborhoods and infrastructure deterrents; bicycle streets with priority over cars); *'Bike parking'* (e.g. large supply of good bike parking; improved lighting and security of bike parking facilities); and *'Coordination with public transport'*.

Gössling (2013) mentions 'Command-and-control measures' as one of the measures presented by the city of Copenhagen. The 'Command-and-control measures' are divided into four categories: Physical infrastructure improvements (e.g. green cycle routes; cycle super highways; new bicycle tracks and curb ramps connecting elevated cycle tracks with roads; widening cycle tracks for greater capacity; layout of tracks based on perceptions of safety; adjusted garbage bins for cyclists; parking spaces for cargo-bikes); Comfort and service improvements (e.g. green wave for cyclists on certain routes); Technology development (e.g. LED sensors at high-risk intersections to warn approaching vehicles for cyclists); and Regulations (e.g. one way street and limited parking spaces for cars; new norms for bicycle parking). As a result of these measures in Copenhagen, a considerable growth of bicycle share has been discovered.

Bernhoft and Carstensen (2008) found that the existence of smooth cycle paths including safe crossings and intersections was obviously the most important outcome regarding safety and comfort. Van der Waerden and Timmermans (2007) investigated the effect of several infrastructural measures being influential on the propensity to cycle, or whether these certain measures would either increase, decrease or have no effect on the frequency of bicycle usage. Börjesson and Eliasson (2012) conducted a cost-benefit analysis in Sweden and did find a considerably higher valuation for travel time savings by cyclists than any other mode. Two experiments were conducted: One for the value of time savings and cycle paths (i.e. the value of time of a bicycle on a street, bike path or of an alternative mode); and Second for the value of intersections and bicycle parking (i.e. the value of bicycle parking, of waiting time at intersections or of one signaled intersection, in addition to the delay). A remarkable difference was found in the value of time for the results between long and short distance trips. People are less willing to take the bicycle for longer distances since they might require a shower at their destination. Besides that, the value of time is becoming more important when there is a certain appointment or time constraint at the destination, making the bicycle less preferred above the car as an alternative (Akar & Clifton, 2010).

2.3. Aspects Influencing Bicyclists' Route-Choice Behavior

Route characteristics not only influence the propensity to cycle or not, but also affect people's route-choices. Geographical Information Systems (GIS) are often used to model these routes based on origin and destination points, e.g. home and work. Dalton, Jones, Panter and Ogilvie (2014) investigated how the actual taken routes differ from modelled routes and what characteristics are responsible for the deviances, using GPS systems. Several other researchers used GPS systems to find utility values for several route characteristics (e.g. Dill & Gliebe, 2008; Papinski et al., 2009; Hood, Sall, & Charlton, 2011; and Milakis & Athanasopoulos, 2014).

It is often being surmised that the shortest route is the prioritized or the most preferred route in comparison to other routes, though many researchers ponder the value of time or trip time reliability in route-choice decisions (e.g. Abdel-Aty, Kitamura, & Jovanis, 1997; Yang & Mesbah, 2013; Liu, Recker, & Chen, 2004; Gan & Bai, 2013; and Ehrgott, Wang, Raith, & Van Houtte, 2012) An important finding by Dill and Gliebe (2008) was that cyclists do not necessarily cycle on the shortest route. The research turned out that although the shortest routes consisted for 36% of roads without bicycle facilities, only 19% of the distance of bicycle trips was cycled on these roads. Roads including bicycle facilities showed an increase in observed bicycle miles relative to the shortest path, meaning that the existence of bicycle facilities are being valued higher than only the shortest route distance. A comparison between planned and observed routes in the study of Papinski et al. (2009) showed that 20% of the participants deviated from the planned route. A possible reason for this deviations is the familiarity with the area and the routes. Home to work trips are usually considered as fixed routes based on habits. Results however, show that road users with much knowledge of the area feel more flexibility towards the planned route, where regarding commuters other attributes such as avoiding road congestion trigger planned route deviation even more. As figure 1 exemplified earlier, the traffic patterns are based on the availability and perception of existing infrastructure and its characteristics or attributes.

Sener, Eluru, and Bhat (2013) make a distinction between aggregate and dis-aggregate studies. Aggregate studies focus more on the effect of bicycle use measures on certain routes and the relationship with the route's characteristics, for instance the increase in bicycle users on a link. These results might be interesting when comparing results of bicycle usage between different cities. Most studies however consider dis-aggregate behavior, looking at each individual cyclist and its perception of the different route characteristics. They emphasize that earlier research does not consider a whole comprehensive list of attributes, consisting of all aspects. Huisman and Hengeveld (2014) explain the traffic market with the same distinction of factors as described in previous section in order to create a complete list of attributes. The same structure is used for this section concerning route-choice decisions.

2.3.1. Trip purpose

Although figure 1 assumes that the trip market (i.e. trip purpose) has no direct influence on the traffic market (i.e. route-choice decisions), there are some researches available where trip purpose is properly seen as an influencing factor for route-choice decisions (Suzuki, Kanda, Doi, & Tsuchizaki, 2012). Yang and Mesbah (2013) investigated the relative importance of bicyclists' route choice factors. They made a distinction in trip purposes due to the large variety of preferences of each group of cyclists. Commuter cyclists, of which's trips consist of home to work or study destinations, prefer less travel time and lower traffic volumes, whereas recreational cyclists prefer scenery and roadway grades. They mention that travel time is the most important influential attribute for commuter cyclists. Regarding route-choice preference for utilitarian trips, Dill and Gliebe (2008) found that participants rated minimizing trip distance and avoiding high amounts of vehicle traffic with the highest importance. The existence of a bicycle path or lane and reduction of waiting times at traffic lights or traffic signs was also valued relatively high. Furthermore, there was a difference in behavior observed between the trip to work and the trip back to the origin.

2.3.2. Demographic factors

Dill and Gliebe (2008) observed a difference in gender's preferences. Besides different route-choice behavior, also speed differences were observed by gender. Women have different perceptions of safety than men and older people tend to avoid high intensity junctions and intersections (Huisman & Hengeveld, 2014). In contrary to the latter, Bernhoft and Carstensen (2008) did not observe a remarkable difference in behavior between different genders. They did however also find a difference in valuation of certain attributes amongst different ages. Older aged cyclists ranked a more direct route higher than the fastest route, while younger cyclists ranked both directness and fastest route as the highest valued attributes, followed by the existence of a cycle path. A possible explanation for these differences might be again the higher valuation of safety by older people. Stinson and Bhat (2003) also found that older people are more sensitive to comfort and traffic conditions.

Besides *'Age'* and *'Gender'*, hardly any other demographic attributes are notably used in many other researches concerning route-choice decisions. Sener, Eluru and Bhat (2013) include *'Employment'* to the list of demographic attributes, though this is to gather more insight in the trip purpose and destination. Dalton et al. (2014) use a rather comprehensive set of attributes, including *'Work type'* (i.e. sedentary or standing); *'Health'*; *'Physical condition'*; *'Household composition'*; and *'Home ownership'*. Yang and Mesbah (2013) also add *'Marital status'*; *'Education'*; and *'Occupation'.* Dill and Gliebe (2008) consider *'Income'* as well. Stinson and Bhat (2003) found that higher income and older aged people felt less sensitivity for travel times.

2.3.3. Social cultural factors

As mentioned in section 2.2.3, social cultural factors consider people's *'Perception'* and *'Attitudes'* towards certain routes as influential factors for route-choices. *'Health consciousness'* will for instance encourage people to be willing to cycle longer distances to reach their destination. Beheshtitabar et al. (2014) add *'Attractiveness'* as influential for route-choice decisions. This however can be considered as an aggregated term consisting of several traffic and transportation factors. The attractiveness in specific, says something about the aggregated value of the route characteristics, such as perceived safety at night or enjoyable scenery (Huisman & Hengeveld, 2014). *'Habit'* could also influence a person's choice for a specific route. Dalton et al. (2014) included *'Mode preference'* as a social cultural factor. Mode preference was described as the percentage of which mode was used for commute trips on average. Other researchers included this as *'Bike use frequency'* (Milakis & Athanasopoulos, 2014; Menghini, Carrasco, Schüssler, & Axhausen, 2010; and Yang & Mesbah, 2013). Note that mode preference is considered as a traffic and transportation factor in the mode-choice section as well.

2.3.4. Spatial economic factors

Working times and schedules affect the route-choices in a certain way regarding spatial economic factors (Dill & Gliebe, 2008). Time pressure might lead to cyclists taking another route to reach their destination. Sener et al. (2013) mention *'Work schedule flexibility'* as employment related characteristics. Dalton et al. (2014) consider a difference between *'Urban and rural'* environment. Besides building density, Milakis and Athanasopoulos (2014) describe the *'Accessibility to activities'* as the density of activities in the surroundings, the *'Accessibility to urban parks'* and *'Centrality'* of the route.

2.3.5. Physical factors

Physical factors are not considered by many researchers. Huisman & Hengeveld (2014) mention natural barriers e.g. steep hills or rivers as factors which influence the taken route. These *'Natural barriers'* can obstruct the shortest or most direct route. Furthermore, *'Darkness'* at night can also affect someone not to choose for a certain route. Weather conditions are not mentioned regarding route-choice decisions, but one could imagine that for instance wind speed might be influential on long distance, inter-municipality fast cycle routes.

2.3.6. Traffic and transportation factors

Figure 1 described that the existing infrastructure and its attributes affect the actual traffic patterns, hence route-choice decisions are mainly affected by traffic and transportation factors. The route-choices depend on the *'Quality of the infrastructure'*; and the *'Location of the infrastructure'*. Also the *'Directness'* between origin and destination is of great influence. Here, the *'Perception'* of for instance directness is also important to take into account. One route might be the shortest modelled route, though a cyclist might perceive another route as the shortest route. The *'Distance'* of a trip, *'Travel time'* and *'Travel time certainty'* are key attributes which are used for many route-choice related studies (e.g. Abdel-Aty et al., 1997; Hyodo, Suzuki, & Takahashi, 2000; Yang & Mesbah, 2013). Liu et al. (2004) found that smaller travel time variabilities are valued higher than a reduction in total travel times. Beheshtitabar et al. (2014) did not consider travel times, but only distances while assuming a fixed speed of cyclists.

Krizek, El-Geneidy and Thompson (2007) investigated the propensity of a bicycle trail in the USA based on the shortest path and how far cyclists are willing to travel for the benefit of it on their route. They found that bicyclists were on average willing to cycle 67% longer distances in order to include the trail on their route. Dalton et al., (2014) investigate *'Car ownership'*; *'Road occupancy'*; and *'Intermediate destinations on the route'*. Dill and Gliebe (2008) describe *'Experience with the transportation mode'*, which has a relation with the perception of safety. Stinson and Bhat (2005) observed a large difference in the influence of safety aspects on experienced and inexperienced cyclists. Safety aspects did have significant less impact on higher experienced cyclists. Chataway et al. (2014) focus more on this *'Perceived safety'*; and *'Fear of traffic'*. Broach, Dill, and Gliebe (2012) provide further insight in these perceptions, stating that *'Personal experience with trip characteristics'* does also influence route-choices. Even when using a stated preference survey, presenting visualized situations, these biased perceptions and experiences of respondents play a role.

Milakis and Athanasopoulos (2014) describe more environmental aspects such as *'Green zones'*; *'Scenery'*; and the *'Quality of architectural scenery'*. They also describe the accessibility to other modes of transport e.g. the *'Accessibility to public transport'* as influential for route-choices. This does not only change the route-choice, but also affects the destination (i.e. a public transport station) and affects the mode-choice as well. Stinson and Bhat (2003) add *'Bicycle facility presence'*; *'Motor vehicle characteristics'*; *'Parking facilities'*; *'Topography'*; *'Parking controls'*; and *'Adjacent land-use attributes'*. They further elaborate these factors in depth, providing a more precise definition of comfort and safety perceptions.

2.3.7. Comfort aspects

Regarding route-choice decisions, more in depth explanations are provided concerning comfort aspects. Where regarding mode-choice decisions often a basic explanation is given of comfort and safety perceptions and how these affect the mode-choices, in studies about route-choice the focus is more on the infrastructural measures and their effects. Besides the infrastructural aspects, the traffic situations are also more extensively described. Chataway et al. (2014) explain that the safety perception and the fear of traffic is also dependent on the situation of *'Mixed traffic'*. Hunt and Abraham (2007) mention mixed traffic as an alternative for the existence of a bicycle lane or path. Stinson and Bhat (2003) found that cyclists try to avoid roadways where pedestrians and cyclists use the same facility. More researches focus on *'Traffic speed'* and *'Traffic intensity'. 'Junction density'* is also an aspect which is considered in some researches (Milakis & Athanasopoulos, 2014; and Caulfield, Brick, & McCarthy, 2012).

Winters, Davidson, Kao and Teschke (2011) also consider *'Traffic noise'* and *'Air pollution'* as influential on route-choice decisions. A large amount of other route-choice studies mention the *'Number of stop signs'* and *'Number of red lights'* on a route (e.g. Yang & Mesbah, 2013; Menghini et al., 2010; Dill & Gliebe, 2008; and Stinson & Bhat, 2003). While the presence of signalized crossings is an aspect influencing the perceived safety, the amount of red lights affects the perceived comfort of a route by the level of continuity of the route. Hence, there is a close interrelation between safety and comfort. The *'Junction type'* has a strong influence on the perceived safety of a route (Parking, Wardman, & Page, 2007). Stinson and Bhat (2003) used a stated preference survey and found that commuter cyclists prefer the shortest route, however tolerate any travel time increases to use bicycle facilities. Besides that, commuter cyclists tend to avoid turns, hills, high intensity arterial routes or off-road routes and prefer traffic signals as a way of traffic control. Infrastructural aspects which are mentioned are: *'Automobile lane width'*; *'Number of driveways providing access to the link'*; *'Width of bicycle lane'*; *'Right hand lane'*; *'Separate path'*; and *'Pavement quality'*.

Furthermore, Yang and Mesbah (2013) add the influence of the *'Presence of facilities and amenities'* (e.g. toilets; showers; changing rooms; bike storage; drinking tap; etc.); *'Street lighting'*; *'Turn frequency'*; *'Gradient'*; and *'On-street parking'*. Turn frequency is translated as *'Legibility'* (i.e. how easily a route is remembered) in the research by Milakis and Athanasopoulos (2014). Next to that, they described ride difficulty with the length of the route and the *'Slope'.* Sener et al. (2013) elaborate on-street parking of cars further by presenting different types of parking, i.e.: *'No parking space'*; *'Angled parking'*; and *'Parallel parking'*. This list is further expanded with the *'Parking turnover rate'*; *'Length of parking area'*; and *'Parking occupancy rate',* however these might influence the mode-choice instead of the route-choice. The presence of on-street car parking was found influential towards route-choice in the research of Sener et al. (2013). Cyclists perceive on-street parking as unsafe due to the danger of opening doors in the situation of parallel parked cars. Dill and Gliebe (2008) investigated the difference in route choice behavior under unique situations: *'Child in a seat'*; *'Child next* *to cyclist'*; and *'Cycling with other people'.* They found that riding with a child influenced the route choice. Besides that, riding with another adult increased the importance of a bicycle lane or path and minimizing distance rose in importance. Carrying a child on the bicycle or riding with a child increased the importance of avoiding intense roads with high traffic volumes significantly. This was also significant for avoiding steep slopes.

2.4. The Current Practice of Transportation Modelling

Many decision making processes in different fields are supported by models. These models are basically consisting of the key relationships between factors based on the data which is available and are used to provide a good understanding of the current situation and how this situation might evolve in the future, with or without certain measures or changes undertaken (Hensher & Button, 2008). It is of major importance for the model developers to be able to isolate the key factors that influence the model outcome. Although computational capabilities have increased enormously in the past recent years, it is still and will remain impossible to take every influential factor into account. The main purpose is to simplify the model in a certain way that it aids the analysis by encapsulating the important determining factors and providing the ability to explore the consequences of particular policies or strategies while still being able to be handled (Bonsall, 1997). Hence, transportation modelling is not transportation planning as it is just to support the planning and its process (Ortúzar & Willumsen, 2011).

Hensher and Button (2008) mention the importance of a good understanding of causes and effects in transport decision making. The majority of the users of transport models are not researchers or scientists but policy-makers or consultants who deal for instance with specific infrastructure improvements or developments. Proper planning of these improvements or developments require extensive knowledge of transportation planners on the implications of their actions on the larger transport network. The latter sometimes leads to frustrations on the side of the model developers when sophisticated models are available although are not being implemented in practice (Ortúzar & Willumsen, 2011). The development of transportation theories and models finds its fundamentals in the early 50's, where during the following years the modelling techniques have been improved.

2.4.1. Transportation demand and supply

In the early 50's there was an emphasis on the capacity of the road network on which the demand was based. Over the last 60 years, the environmental aspects have gained more attention, eventually resulting in a shift from focus on growth to restraining further growth (Bates, 2008). The basic concepts of demand and supply originate from economic theory and can be applied to many particular contexts, such as transportation analyses. Bates (2008) mentions an important distinction to be made within the basic demand and supply theory however, because travel can be seen as a "derived" demand instead of a substantial demand. Travel is a result of the desire of people to take part in certain activities in their daily lives at different locations. Understanding the demand requires insight in the distribution of these activities over time and space (i.e. the urban context). Besides that travelling costs time, there are also benefits enjoyed from it. This leads back to the economic theory where both supply and demand are usually treated as functions of cost; in transportation research translated to 'generalized cost'. Bates (2008) describes generalized costs as a linear combination of time and money, i.e. the value of travel time savings and furthermore mentions the ability to represent it in any other multidimensional vector containing a variable which impacts travel decisions. People base their decisions on the benefits they will enjoy from it, taking the generalized costs into account, depending on certain available resources and opportunities (Button, 2014). Hence, travel behavior is influenced by travel demand.

As explained in the previous sections of this chapter, travel behavior is what people do, how they behave and which transportation mode they choose for their travel. It is exactly what travel data e.g. GPS data reflects and what transportation planners tend to forecast with their models. Travel demand in this, is the part which reflects how people will behave under different circumstances and in different scenarios with various transport facilities to their availability (Button, 2014). In other words, travel behavior depends on travel demand, though travel behavior is not only influenced by the demand for travel, but also by the supply of existing infrastructure and facilities. The maximization of utility does not only count for road users, but is also important for transportation planners. Careful and considered decisions focusing on maximization of advantages of new infrastructure or facilities while minimizing costs and undesirable side effects have gained a lot of attention in the past recent years (Ortúzar & Willumsen, 2011).

The fundamental concepts of most of the widely used models are based on the utility maximization theory. In the latter is assumed that individual's behavior is a result of an attempt to maximize their net gain, or minimize net loss from each decision. The process of choosing the best option is called utility maximization. During the decision making process, trade-offs are made between various relevant attributes (for instance a selection of attributes which are provided in sections 2.2 and 2.3). These trade-offs are then represented through generalized costs (Bonsall, 1997). Besides utility maximization, equilibriums are part of the basic concepts of modelling work. Many models consist of certain rules which bring the system eventually in equilibrium. An example of a model equilibrium is the distribution of traffic on several links. If congestion occurs on the shortest route due to increased traffic flows, a decrease in traffic speed will also occur, resulting in a travel time delay. Because of this delay on the shortest route, other routes will become as attractive as the shortest route due to the absence of any congestion. The model will then bring the system into equilibrium by distributing the traffic load in such a way on the links, in order that travel times on all of these links are equal.

Another fundamental concept is the aggregation of individual's choices to estimate population's decisions. The performance of a traffic system is mainly determined by the decisions by individuals, though measured by the abstract totals (Bonsall, 1997). Although aggregation of data is widely applied in many models used by current transportation planners, there is an increasing attention for models which simulate each individual traveler separately and distinguish trips into 'tours' and 'chains' (see section 2.4.3).

2.4.2. The four-step model

The level of demand is clearly not only dependent on the costs related to the transport system, but also on demographic factors such as population and external changes such as land-use. These factors change over time, making the level of demand also time dependent. Assumptions about the future characteristics of these factors are translated into different scenarios to study (Bates, 2008). Since different individuals have different perceptions and needs or activities, they do also have a different demand. For instance household composition and employment play an important role in the activities which take place on a daily basis. As mentioned before, it is not only important to forecast the activities which take place at which time, but it is also important to know the locations of origins and destinations. The population with different types of persons is divided into 'zones' in traditional models. These zones affect the demand and have their own environmental characteristics. One model type in which interrelations are assumed between land-use and travel behavior is the "land-use transport interaction model" (Wegener, 2014). The most common used model however, called the "four-step model" (also known as the "four-stage model", "four-phase model" or "classic transport model") maintains a distinction between external, demographic effects and direct influences on the transportation system (Bates, 2008). This four-step model is also referred to as the "trip-based approach" (McNally & Rindt, 2008).

The four-step model also starts with the distribution of a zoning and network system and considers the collection and coding of planning, calibration and validation of data. This data includes base-year data about the population composition of each zone in the study area, economic activity e.g. employment, shopping space, educational and recreational facilities (Ortúzar & Willumsen, 2011). McNally (2008) describes this as an 'Activity system' which represents the socio-demographic and land-use data for the zones and a 'Transportation System' which represents the transportation network. The four-step model considers the following steps in the transport process: *'Trip generation'*; *'Trip distribution'*; *'Modal split'*; and *'Assignment'*. These steps were earlier represented in figure 1 in section 2.1 of this chapter. Although this model represents such an important position in the history of transport demand modelling, it has been widely criticized because of its fixed sequential property (Bates, 2008). Nowadays however, this fixed sequential application of the model is mitigated by the introduction of feedback allowance in the model, which brings the model in equilibrium (Boyce, Zhang, & Lupa, 1994). Travel decisions are not based on this sequence of steps, but the order of the steps is usually a result of the utility function assumed by travelers (Ortúzar & Willumsen, 2011). Besides the fixed order of steps, also the level of aggregation has changed. The number and composition of zones in the area mainly determine the variation of trips being distributed. Bates (2008) states that therefore, the criticism on the four-step model is not by definition based on the model's concepts, though more on the way the model is being applied in practice. The four-step model is illustrated in figure 2. During the first step of trip generation, daily travel is being defined at a household or zonal level based on various trip purposes or activities. This explains the trip-based, aggregated property of the four-step model. The zonal data as described in figure 2 is used to estimate the number of trips being generated and attracted by each zone in the study area. In the second step, these trip productions are being distributed over space, based on the trip attractions and certain resistance factors such as time and trip costs. Personal trip demands are then assigned to trip tables or matrices. Thereafter, the alternative transportation modes are assigned, reflecting the trip tables, resulting in a modal split. The last step consists of route-choice, where the modal trip tables are assigned to the existing mode-specific network.

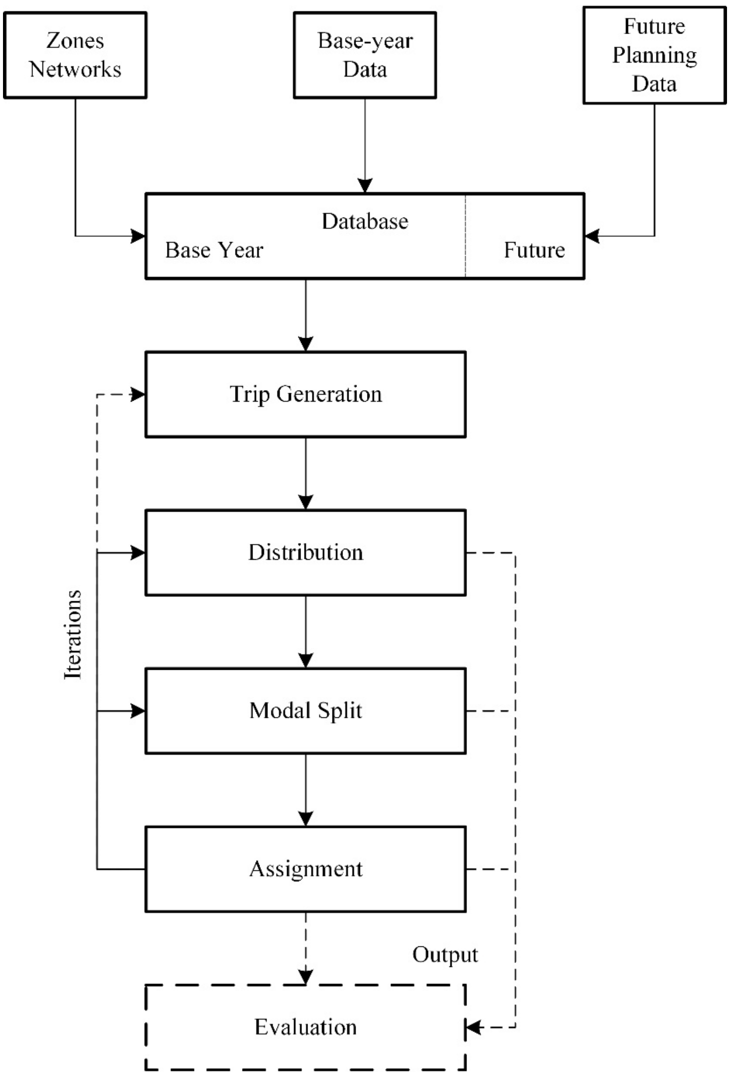


Figure 2: The four-step model and its iterative processes (Ortúzar & Willumsen, 2011, p. 21)

McNally (2008) only considers equilibration on the route-choice assignment and feedback on all steps excluding trip generation. Ortúzar and Willumsen (2011) do consider an iteration or feedback on the trip generation. This is moreover explained by the possible reactions with which a traveler will respond in situations with increased congestions on e.g. the shortest route. The traveler might in this case choose for another route, by taking advantage of other links on the network with less congestion. This form of equilibration has been explained before. Another iterative process in the four-step model might be that the traveler will change its mode-choice due to the increased congestion. Again another option might be to choose another time of departure to avoid congested links. They furthermore mention the destination choice as being dependent on the level of congestion. One might be willing and able to choose for another trip destination due to certain route characteristics. The last decision mentioned by Ortúzar and Willumsen (2011) is the choice to change the trip frequency and combine multiple activities in one journey. More recent approaches in transport modelling consider choices of trip frequency, destination and mode choice in one single model. Besides that, there are other approaches which emphasize the roles of household activities and the travel decisions under multiple constraints (Ortúzar & Willumsen, 2011). McNally (2008) furthermore mentions that the four-step model is definitely not the state-of-the-art within transport modelling, though is being applied so extensively due to its very practical properties and financial limitations in practice. The next section describes the more state-of-the-art approach regarding development in transportation science and forecasting, further elaborating on these household activities in the activity-based approach.

2.4.3. The activity-based model

As mentioned in section 2.4.1. of this chapter, travel is seen as a derived demand, since travel with utility purpose in particular is something which is done to satisfy a certain need at a different location. Thus, trips are made to undertake multiple activities at different locations over a period of time. The four-step model which is described in previous section, also known as the trip-based approach supports transport systems analyses by travel demand and network performance procedures and determining flows which form an equilibrium on the network supply. Ortúzar and Willumsen (2011) describe the use of zonal production and attraction as a simplification of handling the link between travel and activities, i.e. the reason behind travelling. When looking at trips on its own, the behavior of combining certain activities at different locations over time are not considered.

A trip is being described as a movement between two locations which can be executed by one or more modes of transport. A tour is described as a sequence of trips starting and ending at the same location, forming a closed loop. Next to that, a trip chain is also a combination of several trips but does not end at the same location as the starting point (Ortúzar & Willumsen, 2011). Tours are mainly classified by their most relevant purpose, such as work or education in production and attraction models. Figure 3 shows how Ortúzar and Willumsen (2011) describe the tours of four persons.

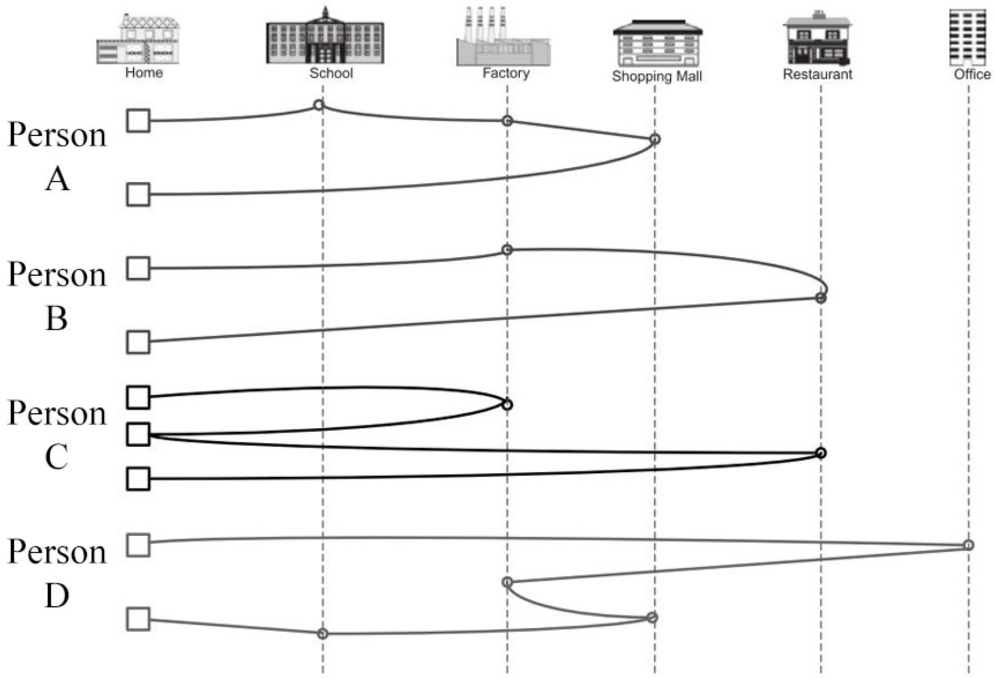


Figure 3: Four different persons and their activity schedules described by tours (Ortúzar & Willumsen, 2011, p. 475)

Person A for instance, makes a trip to work, though stops by the school first and directly after work does his shopping at the mall before turning back home. The classic four-step model would not easily be able to describe these movements as separate trips. The movements by person C however would result in two trips from home to work and from home to the shopping mall in the four-step model. This figure shows the limitations of the classic four-step model where these interrelations are not considered at all. Besides the movements, the choice for a certain transportation mode does also affect the tours. Once during the first trip e.g. from home to school is chosen for the car as a transportation mode, it can be stated in all probability that the tour is continued with that same mode. From another perspective and in contrary to the latter, public transportation is often combined with cycling as a common mode for pre-transportation.

Household characteristics are strongly related to activity demand: Households influence the made decisions; their characteristics (e.g. size, relationships, age, etc.) influence the effects; and children in particular have great influence on the constraints on others within the household (Ben-Akiva & Bowman, 1998). Many more researchers emphasized the need to consider the household composition and their activity schedules in order to be able to capture the behavior of members of the household and the interaction between their trips, tours and activities (e.g. Kitamura, 1988; Axhausen & Gärling, 1992; and Ortúzar & Willumsen, 2011) furthermore give an extensive definition of activities. In short, activities could be either short or long term demands and as well be physiological or psychological demands (e.g. sleeping). They involve time, duration, location and a certain mode choice. Mandatory activities such as going to work offers limited flexibility in terms of time, location and duration. Activities can be scheduled individually or with other persons and may therefore be constrained to the availability of those other persons. Bifulco, Cartenì and Papola (2010) consider a weekly household activity model to start with. From there on, a daily household activity schedule is defined, further converging to activity patterns and a trip chain model at the end.

Longer tours, combining several activities such as shown in figure 3 are more complex and currently less frequently found than shorter tours. Ortúzar and Willumsen (2011) state however, that congestion reduction policies might lead to more complex tours being made, since tours which combine all day-scheduled activities result in less activities than a separate tour back home for each activity. The full specification process of present and future population characteristics is called 'population synthesis'. This is a more detailed approach of spreading addresses than used in traffic zoning in the four-step model. An intermediate approach to the latter however, is the creation of behavioral groups within each zone instead of investigating each individual separately. Base year data is collected from Household Travel Survey results and is used to estimate future year characteristics. Although sample enumeration is basically working on a disaggregate level, zonal enumeration as used in the four-step model can also be applied with many different segments of the population in each zone, thus expanding the sample of representative household types.

Davidson et al. (2007) explain the major advantages of activity-based models over the traditional four-step model. Where the four-step model bases its trip attraction on zonal characteristics, the activity-based models introduce a distinction between primary and secondary activities. At the stage of trip distribution using the four-step approach, non-home-based trips are being modelled independently, while the activity-based model links the home-based trips to the non-home-based trips. Besides that, the activity-based models provide more consistent mode-related decisions than the four-step approach. The activity-based models furthermore allows to measure policy intervention effects during congestion peaks, since the incorporation of time-of-day choices for the activities. Rasouli and Timmermans (2014) also mention the promises of activity-based modelling and the lack of behavioral realism of the four-step approach.

Most of the activity-based models are microsimulation tour-based models, supported by a random utility choice-modelling framework (Ortúzar & Willumsen, 2011). The tour-based models provide more consistency in destination, mode and time of day choices than trip-based models (Yagi & Mohammadian, 2010). Currently, there are some experimental models developed which tend to treat issues with greater realism by representing behavior and negotiations within the households. These models belong to the group of 'Computational Process Models' and differ from other microsimulation methods by not using utility-maximization rules, yet by using 'if-then' rules. Examples of models in this field are SCHEDULER; AMOS; ALBATROSS; and PlanomatX. Algers, Eliasson, and Mattsson (2005) mention ALBATROSS as a valuable improvement, because of the better underpinned behavioral mechanisms. Ortúzar and Willumsen (2011) mention that these models will probably remain experimental, i.e. used for research purposes for a while, before being implemented in practice by transport planners. This is due to the complex properties of the model, requiring very context-specific adjustments. Bowman and Ben-Akiva (2000) also state that further model refinements are necessary for operational implementation, however it has great potential for improving travel forecasts. Besides the use of activity-based models for transport planning, there are also other applications investigated e.g. in combination with air quality models (Beckx et al., 2009) or the specific focus on freight transport (Liedtke & Schepperle, 2004). Algers et al. (2005) emphasize the unclear future demand of transport modelling and the direction which transport research should follow. Despite the increased availability of data (e.g. GPS data and GIS (Wang & Cheng, 2001) or travel survey data (Witlox & Tindemans, 2004)) which is very suitable for activity forecasting, McNally and Rindt (2008) mitigated the approach's potential on the shorter term due to the criticism on a full replacement of the four-step model and the lack of an imminent model applicable for practice applications. Some models have found practical applications, for instance the ALBATROSS model is fully operational on a national scale in The Netherlands (Arentze & Timmermans, 2008). There are several other models available, though they differ significantly (Rasouli & Timmermans, 2014). Although there are many contributions to the state-of-the-art in the field of transportation research, only a marginal value to the state-of-the-practice is observed (McNally & Rindt, 2008). Progress on information of social networks, knowledge on how to handle Big Data and perceptions of location privacy will support activity-based modelling in transportation related issues (Miller, 2014).

2.4.4. The marginal position of the bicycle in current traffic models

Currently, not only the model types which are applied in practice, though also the modelling techniques and processes require attention for further development. 'Human factors' as Hoogendoorn and Meurs (2015) call it, are still missing in many operational traffic models. Examples of human factors are perception, attention, information processing, decision making processes and making mistakes. These factors are important to take into consideration when analyzing the effects of a certain mobility measure.

De Graaf, Hoogendoorn and Barmentlo (2015) mention that almost all municipalities and regions in The Netherlands are currently using strategic traffic models to support their mobility policies. Unfortunately, these models do not consider the slow-traffic flows yet, while these slow modes are becoming more important in the urban scenery now and in the future. De Graaf, Hoogendoorn and Barmentlo (2015) distinguish two problems within the current modelling processes which constrain proper slow traffic forecasting: The current level of detail in the traffic models is not suitable for modelling cyclist and pedestrian behavior, i.e. the descriptive part of the modelling process; and the estimation of behavioral parameters for slow traffic require considerable improvements, i.e. the explanatory part of the modelling process.

Regarding the descriptive part, the scale on which traffic modelling is taking place has changed. Where the traffic flows were earlier (and still are) modelled on a regional level, this regional scale does no longer satisfy the needs of slow traffic modelling, which consists mainly of short trip distances. There are developments in the traditional models which are applied in practice however. These developments mainly consist of the above mentioned change of scale, further refining each 'zone' in the model to more land-use functions. For instance regarding trip generation, 'education facility' is separated into different school types and 'retail facility' is now defined as a type of shop or shopping center. Concerning the modal shift, there are distance classes defined more in detail, including e-bikes separately from normal bicycles. Next to that the bicycle facility networks are further refined using quality indexes concerning route directness, distance, level of comfort and number of stops.

Regarding the explanatory part of the modelling process, more insight is desired in the effects on behavioral trends as a result of taken measures. Here, the traditional 'gravity-models' are no longer sufficient and so-called 'discrete-choice models' can be used to determine and investigate mode-choice and destination choices (see also chapter 3). De Graaf et al. (2015) emphasize the lack of knowledge of which factors exactly influence bicyclists route- and mode-choice behavior. This furthermore states the purport of the comprehensive literature review on behavioral aspects earlier in this chapter.
There are nationwide research programs started to further elaborate on slow traffic modes. Besides that, more attention has arisen in the field of transport planning on the gap of bicycle integration in current traffic models (CROW fietsberaad, 2015). Progress is being made on traffic models for provinces in The Netherlands, but these are still at an early stage (Verkeerskunde, 2013).

2.5. Conclusion

This chapter earlier started with a comprehensive review of current literature on behavioral aspects regarding mode- and route-choice of cyclists. The first three research questions of section 1.2. can be answered by the summarizing table including the obtained aspects and their ability to be influenced in Appendix A. Many of these aspects affecting mode-choice do also affect route-choice behavior. What can be concluded from current literature is that many of the researchers did not consider an extensive set of attributes and many of them do not further explain the definition of what comfort is or means in general and to cyclists in particular.

As an answer on the fifth research question of section 1.2., a short analysis is conducted on the current practice of transport modelling. The traditional four-step model has a large history in transportation modelling and is, although it is being criticized widely, still the most often applied model in practice. Improvements have been made on the modelling process and the fixed sequence of the four steps has disappeared in many applications. In the field of transportation research, the activity-based models receive more attention. The growing availability of data and increase in computational power provide high potential for the latter modelling technique, but a general applicable activity-based model form is hitherto missing.

Regarding the integration of cyclists in current traffic models, many improvements still have to be made. The operational traffic models are based on car traffic and do not sufficiently consider slow modes of transport yet. The level of detail has to be changed, as well as the model scale. Zonal activities should be defined in more detail and more insight is required in behavioral aspects. Discrete choice models could be used to estimate these behavioral parameters. GPS data is moreover very suitable to analyze 'hidden paths' (i.e. routes which are not modelled yet in the network layers of the traffic models, though which are of relevant importance in route-choice decisions) and to compare modelled routes with actual taken routes. This literature review emphasized the importance of further research on bicyclists behavior and exemplified the gap of slow modes in current traffic models and the potential of activity-based solutions.

3. METHODOLOGY

3.1. Introduction

Chapter 2 started with a description of the traffic and transportation market concepts. As figure 1 in that chapter explained, the traffic patterns are dependent on the supply of infrastructure and its attributes and scheduled activities. Heading back to section 2.4.1. about demand and supply of infrastructure, a comparison can be made with other fields. In the field of marketing research, the direction is mainly toward predicting how these consumers will react to the availability of new coming products or modifications of existing ones (Carson et al., 1994). This is comparable to the situations in transportation planning, where insight in the effects of new planned routes or improvements of alternative routes on existing connections is demanded. Understanding the behavioral responses of individuals and aggregated groups of individuals to the actions of transport planners or policy makers on a governmental level will always be of interest to a large extent of society (Louviere, Hensher, & Swait, 2000). Decision makers are looking for well substantiated assessments of alternatives and need to be aware of advantages or benefits of certain made costs or investments. Stated preference or stated choice techniques were therefore introduced in the field of transportation research in the end of the 1970s (Ortúzar & Willumsen, 2011).

As already mentioned in section 2.4.4., there is hardly any traffic model application providing such a substantiated assessment of route alternatives for cyclists yet. New infrastructural bicycle facilities require large investments, hence the importance for a sound assessment should not be underestimated. This chapter further explains the fundamentals of decision making. The concepts of the choice theory are further elaborated in the next section of this report about choice modelling, including principles of the random utility theory. After the elaboration of the methodology, the model specification and experimental design for the research are explained. Thereafter, the data collection method is described, followed by an overviewing conclusion of the research model.

3.2. Choice Modelling

Decision making consists of situations in which a choice has to be made between multiple alternatives within a so-called choice set. Placing the decision maker in the position in which he or she has to make several decisions, allows researchers to investigate interrelations between the made choices. Development of the choice set is a complex and time consuming task which should not be underestimated (Hensher, Rose, & Greene, 2015). It is important to consider very accurately what influences the choice of one alternative over another. Hence, the literature review in chapter 2 already provided a comprehensive overview of influential attributes on individual's choices. The so-called utility of a certain alternative is derived from the properties or characteristics which the alternative possesses, rather than the particular alternatives itself (Louviere et al., 2000). An exception to the latter however should be noted, since there are 'labeled' and 'unlabeled' experiments. This will be further explained in section 3.4.2. of this chapter.

Within transportation research two primary sources of choice data exist: revealed preference and stated preference. The former source i.e. revealed preference is based on real made decisions in an existing situation. An example is the use of GPS data to observe route-choice of people (e.g. Broach et al., 2012). Revealed preference data is a proper form of data to create the current market equilibrium, explaining how people act in the environment as it is at the moment. The observations which can be made however do also only depict the attributes which are existing. Besides that, there are also many attributes which might not be observed by the analyst, though which might have been of influence to the decision maker. The fact that the revealed preference data is related to real made choices, it has a high reliability and validity, though also brings complexity to analyze (Louviere et al., 2000). Stated preference on the other hand, can be used in a more flexible way by introducing virtual or hypothetical choice situations. It can, as already mentioned be used to find preference weights for separate influential attributes and can be used to 'label' certain alternatives in the choice set. In order to gather reliable data, it is of major importance to create a good understanding at the side of the respondent, which means creating realistic choice alternatives to obtain the respondent's commitment to complete the tasks (Louviere et al., 2000; and Hensher et al., 2015). Stated preference has the major benefits of providing the ability to predict what happens in future situations that do not yet exist. It is therefore preferred for this research since more insight in the effectiveness of newly planned bicycle routes and facilities is demanded.

Discrete choice models describe decision makers' choices among alternatives in a choice set (Train, 2002). The choice set should ensure all possible responses being able to be chosen when a certain change in the decision environment occurs. They explain this by the example of mode-choice decisions. Where many researchers 'force' respondents to choose between different modes of transport given a situation, it might actually be the case that in reality this respondent stays with, for instance, the car as a mode of transportation and changes his or her departure time to avoid congestion instead of taking the bicycle as he or she would have answered in the choice experiment. It is therefore always important to consider the whole decision making process and represent a realistic decision environment in the research. Principles of choice theory are further explained in the next section.

3.2.1. Choice and utility theory

Decision making does not always consist of conscious actions. Some decisions, e.g. which route to choose from home to work are made subconsciously. For an analyst it is therefore even harder to explain choice outcomes fully, since the available data of an individual's choice is never complete. Besides the reasoning of an individual's decision making, there are also differences to be noticed among different individuals or groups. This variability of reasoning or taste variations behind made decisions is often called the 'heterogeneity' (Hensher et al., 2015). A distinction can be made between the measured and unmeasured heterogeneity, where the analyst wants to maximize the first and wants to minimize the latter mentioned form of heterogeneity. The objective of choice analysts is to recognize that there is data which is not captured within the scope of the research and that there might be unobserved data which also influences individual's choice behavior.

It is the personal preference of an individual which leads to a decision being made. One might prefer driving a car over using the bicycle as a transport mode, though the attributes, such as experienced convenience, comfort or safety might be the reasoning behind this preference. The respondents need to have a clear understanding of the meaning of the defined alternatives in the choice set (Hensher, Rose, & Greene, 2005). Each attribute within the alternatives has to be expanded with a range of attribute levels, to make it possible to compare the attributes to each other. The numerical measure to each combination of attributes and levels is called the ‘utility’ or ‘level of satisfaction’.

The utility is a measurement of well-being without a natural unit, level or scale (Train, 2002). Holding some attribute levels ‘fixed’ in a choice experiment makes it possible to measure the variability in the utility of ‘non-fixed’ attributes. Again it should be noted that other factors, which are not considered in the research, might be considered as ‘fixed’ attributes by the respondent and might influence the choice outcome. Repeating the steps while varying the attribute levels, enables estimating the utility of alternatives to individuals.
The behavior of individuals trying to choose their most preferred alternative is referred to as ‘utility-maximization’. Given this assumption of utility maximization and the fact that a choice for an alternative of a certain choice set is based on modelled, observed factors and hidden, unobserved factors, the utility U_{iq} for choosing alternative i by individual q is expressed in equation (1) below, taking into account a ‘systematic, observed value for utility’ V_{iq} and a ‘random component’ ε_{iq} which reflects the unobserved factors (Louviere et al., 2000).

$$U_{iq} = V_{iq} + \varepsilon_{iq} \tag{1}$$

Because there is an unobserved utility value, the observed value of utility, V_{iq} is not equal to the alternative utility U_{iq}. Since this unobserved utility factor is unknown to the researcher it is treated as a random factor. The observed or systematic value of utility V_{iq} with alternative i for individual q can be defined as a function of k variables x_{iqk} with parameter estimates β as in equation (2) (Hensher et al., 2015):

$$V_{iq} = f(x_{iqk}, \beta) \tag{2}$$

According to Hensher et al., (2015) equation (2) can be translated to a common used linear function for the observed component of utility:

$$V_{iq} = \sum_{k=1}^{k} \beta_k x_{iqk} \tag{3}$$

Here, a linear relation is assumed for the attributes and the parameter utility function. The observed utility V_{iq} is represented as the sum of the utility weights (i.e. parameter estimates) β_k multiplied with the attribute variable x_{iqk}.

Knowing the utility of the attributes and the utility of a certain alternative, makes it possible to calculate the probability that individual q chooses for alternative i instead of alternative j in the same choice set using the following behavioral model (Train, 2002):

$$P_{iq} = prob(U_{iq} > U_{jq} \; \forall \, j \neq i) \tag{4}$$

3.2.2. Multinomial Logit

Equation (1) in section 3.2.1. already introduced the random utility model which assumes that the utility consists of an observed, systematic utility component and a random component. The observations on choices reveal the individual’s preferences in a discrete categorical manner, over a discrete set of alternatives. The utilities express the intensity of those preferences. Common regression methods are not applicable in this case and more advanced econometric models are required.

Hensher et al. (2015) describe two types of econometric models: 'Probit' and 'logit'. Logit, with the multinomial logit model in particular, is the most widely applied discrete choice model due to its ease of use, its readily interpretability and the closed form (Ortúzar & Willumsen, 2011). The multinomial logit model is also known for its property of assuming that the random component ε_{iq} as in equation (1) is 'independently and identically distributed' (also known as Gumbel or Extreme Value Type 1 distribution) and besides that is based on the assumption of being 'independent from irrelevant alternatives' (Train, 2002). In the latter is assumed that a distribution of choices over two alternatives for instance, is not being influenced when a third alternative is added to the choice set. Note that this assumption brings limitations to the model applicability.

Heading back to equation (4) and further elaborating on the assumption of independently and identically distributed error components brings the following probability equation for the multinomial logit model (Louviere et al., 2000):

$$P_{iq} = \frac{e^{V_{iq}}}{\sum_{j=1}^{j} e^{V_{jq}}} \tag{5}$$

Equation (5) describes the probability that individual *q* will choose for alternative *i* in a choice set with *j* alternatives. This equation can be used for model estimation. Because of the closed form of the model, the maximum likelihood procedure can be applied, as in equation (6):

$$L(\beta) = \prod_{q} \prod_{i} (P_{iq})^{y_{iq}} \tag{6}$$

Here, the probability of individual *q* choosing alternative *i* is displayed with a factor y_{iq}, which can be either one when chosen or zero when not chosen. β is a vector containing the parameters of the model. Equation (6) can be translated into the log likelihood function as in equation (7) using a natural logarithm:

$$LL(\beta) = \sum_{q} \sum_{i} y_{iq} ln\,(P_{iq}) \tag{7}$$

Model significance can be further investigated by using the log likelihood of the so-called 'base model' or 'null model' (parameters are set to zero) with the 'fitted model' (parameter estimates included). A common used statistic to measure how well the model fits the data is the rho-square, or 'likelihood ratio index' as displayed in equation (8):

$$\rho^2 = 1 - \frac{LL(\beta)}{LL(0)} \tag{8}$$

Where *LL(β)* is the log likelihood of the fitted model and *LL(0)* is the log likelihood of the null model. The value of the rho-square can take values between zero and one. Where one is the best fit, though a good model fit is already considered for a value of 0.3 (Hensher et al., 2015). Sometimes an adjustment for the degrees of freedom is applied, where the number of estimated parameters is subtracted from the value for the fitted model in equation (8).

Another statistic to compare the null model with the optimal model is the Chi-Squared statistic as defined by equation (9) (Hensher et al., 2015). If the value of the calculated statistic exceeds the Chi-Squared value according to Chi-Squared tables with the same degrees of freedom, the optimal model is a significant improvement of the null model.

$$\chi^2 = -2\big(LL(0) - LL(\beta)\big) \tag{9}$$

There are modifications and extensions to the standard multinomial logit model which relax the assumption of an independent and identical distribution such as the nested logit model and the mixed logit model. These types of models are not elaborated within the scope of this report, but for further reading, Louviere et al. (2000) and Hensher et al. (2015) are recommended.

3.3. Design of the Choice Experiment

This section describes the processes of the experimental design. The main purpose of this step in the research process is to create an experiment which allows to observe effects of a certain response variable under the condition that other variables have manipulated levels. The generation of such an experiment does not take place in a random way, more importantly it requires a strategic setup process. Inefficient designs might deliver insufficient data as well, which should obviously be avoided. Hensher et al. (2005) mention eight steps in the experimental design process. These steps are illustrated in figure 4 and form the fundamental basis of this research as well. Note that stage 1 to stage 5 might require some iterations.

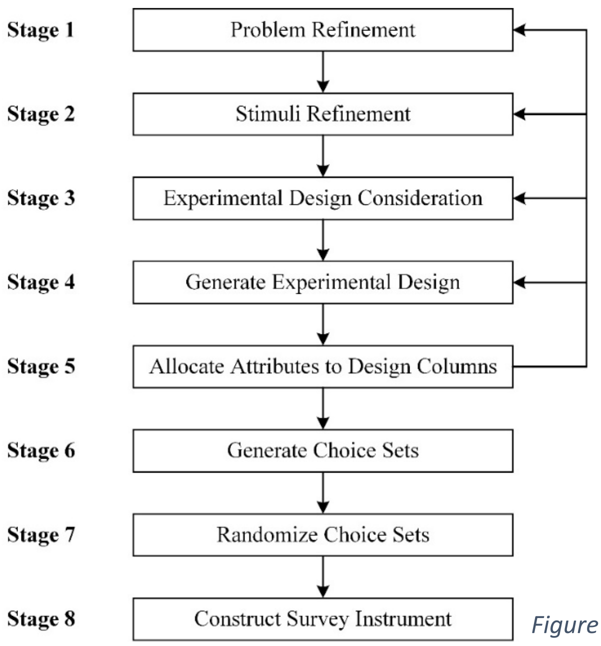


Figure 4: The experimental design processes (Hensher et al., 2005, p. 102)

3.3.1. Problem refinement

The questions of section 1.2 regarding which aspects influence mode –and route-choice decisions have already been answered in chapter 2, providing the theoretical framework and background knowledge on travelers' behavior. Then, the next question which should be answered is to what extent these influential attributes are of significant value to the mode – and route-choice decisions. Having a clear understanding of the research problem is the first part of the experimental design process. Knowing why the research is undertaken makes it possible to avoid irrelevant questions and gives insight in which questions have to be asked and answered (Hensher et al., 2005). Though it is demanded to find the valuations of aspects regarding route- and mode-choice decisions, combining these two tasks in one experiment would be too complex. Hence, the research consists of a separate route-choice and mode-choice experiment. This will be further explained in the following sections. The Practical knowledge and future expectations added the hypothesis that the value of certain attributes differ for normal bicyclists and E-bike users. Besides that, these values probably also differ on long and short distance trips. In order to be able to make statements about cyclists' behavior on several trip distances, the research is divided into two distance classes. Figure 5 shows the separation into different experiments for normal bicycles and E-bikes and both divided into long and short distance classes.

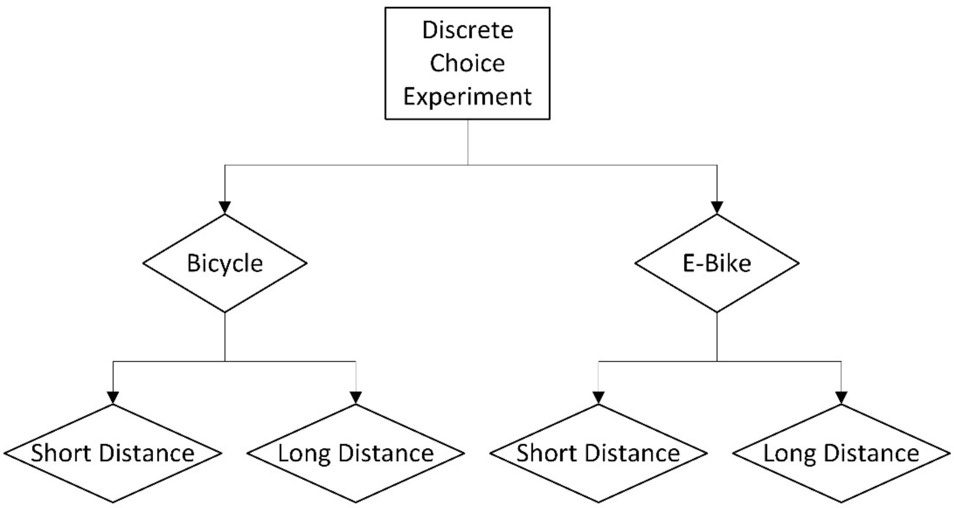


Figure 5: The route-choice experiment and its distinguished bicycle types and distance classes

3.3.2. Stimuli refinement

The second stage of the experimental design process according to Hensher et al., (2005) is the stimuli refinement. The first step in this stage is to refine the alternatives. The respondents should in the end be able to choose an alternative from a complete, though finite set of alternatives which represents each and every possible alternative as would be in a real-life situation. Only then the utility maximization rule is not violated. Hensher et al. (2005) mention several ways to reduce the number of alternatives. One is to exclude the insignificant alternatives and second is to use 'unlabeled' alternatives. As explained in the first stage of the experimental design processes, this research focuses both on to what extend relevant attributes influence mode-choice as well as route-choice decisions. Therefore, the choice experiment is also separated into two parts: a route-choice and a mode-choice experiment.

For the first experiment, unlabeled alternatives are used in the route-choice set. Here, the alternatives themselves do not have a value to the respondent as the so-called 'labeled' experiments do. An unlabeled alternative might be 'route 1, route 2, etc'. The numbers '1' and '2' do not have any intrinsic value to the respondent as the labeled alternatives such as 'car, bicycle or bus' do. For the route-choice experiment the number of route alternatives is limited to two alternatives to choose from. This is done due to the fact that in reality, basically no more than two or three main routes are available to a cyclist traveling from A to B. Besides that, considering a rather comprehensive set of attributes, two alternatives are easier for the respondent to choose from than three alternatives. Hence, two unlabeled alternatives will be presented to the respondent within each route-choice task.

For the mode-choice experiment, a selection of alternatives is made. Hensher et al. (2005) add to this option that this might be a risk, since the analyst decides on forehand which alternatives are significant to be included in the research. Both based on the theoretical framework as provided in chapter 2 and on practical knowledge, this report focuses on three mode-alternatives to study: 'Bicycle; Car; and Public Transport'. Where for the bicycle a distinction is made between E-bikes and normal bicycles. Note that for this experiment, 'Public Transport' is not further expanded into sub-types.

After having defined the relevant alternatives, a more complex step is to define the attributes that will be used in the choice set to describe the alternatives. Attributes are basically the characteristics of an alternative. Each attribute is again described by a number of levels. In the unlabeled route-choice experiment, each alternative is described by the same attributes. In the labeled mode-choice experiment however, the attributes are alternative-specific. Hensher et al. (2005) furthermore mention that ambiguity and correlations between attributes should be avoided. For instance, the correlation between price and quality leads to an unreal situation when the combination of a high price and low quality is presented to the respondent.

Choosing levels of attributes requires attention. Using three or even more levels per attribute allows observation of non-linearity and creates more accuracy, though results also in more complexity. Hence, in this research a number of three levels is chosen per attribute. Besides the number of levels, also the range is important. One would prefer to maximize the range of the attribute levels, while keeping the comparisons between the levels realistic to the respondent.

Table 1: Route-choice experiment (unlabeled) and its alternatives, attributes and number of levels

(E-) Bike Route Alternative	Route A	Route B
Travel Time	(4 x) 3 levels	(4 x) 3 levels
Bicycle Facility Type	3 levels	3 levels
Traffic Speed	3 levels	3 levels
Non Priority Intersections	3 levels	3 levels
Priority Intersections	3 levels	3 levels
Traffic Lights	3 levels	3 levels
Slope	3 levels	3 levels
Pavement Quality	3 levels	3 levels

In this research, each alternative consists of 8 attributes, described by three levels. Other attributes are considered as 'fixed' in the experiment. First, the '**bicycle type'** is being dependent on the most common used bicycle (i.e. Nomal bicycle or E-Bike). The **'Trip Purpose'** is fixed in the experiments, the **'Time of Departure'** is fixed to 'daytime' in the experiment, the **'Weather'** is assumed to be clear and relatively windless, it is also assumed that no **'Travel Companions'** join the trip and no heavy **'Amount of Cargo to Carry'** is applicable. Table 1 shows the non-fixed route-choice attributes which have been selected from the complete list in Appendix A to continue with in the choice experiment.

For **'Travel Time'** four sets of three levels are defined. One short distance and one long distance travel time class for both a normal bicycle as well as an E-bike. Thus, each respondent will only be burdened with three levels for travel time. Three types of on-route intersections are defined as separate attributes. Appendix B provides a complete list of attributes and levels in the route choice experiment. The respondent is asked to make a decision between route A and B, based on their preference. Besides that, the respondent is asked to rate both route alternatives on a five level scale, called **'Route Comfort'**. This way, the respondent provides a definition of 'comfort' which can be incorporated into the mode-choice experiment without resulting in an overly complex experiment. This aspect of route comfort is introduced as a three level attribute in the mode-choice experiment. Hence, the route-comfort forms the connection between the two experiments.

Table 2 shows the attributes which are used in the mode-choice experiment. Again, 4 sets of three levels are defined for **'Bicycle Travel Time'**. There are different levels assigned to **'Car Travel Time'** and **'Public Transport Travel Time'**. Note that the attribute **'Delay'** does not count for the bicycle, **'Parking Facility'** does not count for public transport and the **'Route Comfort'** is only defined for the bicycle as a mode. The same attributes as in the route-choice experiment are considered as 'fixed' in this experiment.

Table 2: Mode-choice experiment (labeled) and its alternatives, attributes and number of levels

Mode Alternative	*(E-) Bike*	*Car*	*Public Transport*
Travel Time	(4 x) 3 levels	3 levels	3 levels
Delay	n.a.	3 levels	3 levels
Parking Facility	3 levels	3 levels	n.a.
Route Comfort	3 levels	n.a.	n.a.

Appendix C shows a systematic overview of the mode-choice experiment and the specific attribute levels. The **'Car Travel Time'** and the **'Public Transport Travel Time'** are displayed as a percentual increase or decrease relative to the bicycle travel time. For the **'Parking Facility'** is assumed that there is either 'no facility', a 'non-secured facility' or a 'secured facility' where the respondents are allowed to consider these facilities as free of charge. For the **'Route Comfort'** attribute, the respondent has to consider his or her own definition for comfort as assigned in the route-choice experiment.

3.3.3. Experimental design consideration

Although there are many experimental designs available, the most general class is the 'full factorial design' in which all possible treatment combinations are enumerated (Hensher et al., 2005). A treatment combination or profile represents a possible alternative in the choice experiment. There are 6561 treatment combinations in the full design of both experiments which makes investigating the full factorial design no option. Therefore, often a 'fractional factorial design' is used.

This report will further elaborate on a fractional factorial design which is, in order to reduce the scope of the research, an 'orthogonal main effects only design'. This design class allows estimation of main effects independently, though leaves the interactions confounded with one another (Hensher et al., 2005). The use of a main effects design as suggested is therefore also a risk, since it is being assumed that all interactions are insignificant, which if not true might lead to sub-optimal results.

3.3.4. Experimental design generation

As mentioned in previous section, a main effects only design will be generated for the research. Designs can be generated using software packages such as SPSS, though existing efficient designs are often also already available. The orthogonal design which will be used in this research is shown in table 3. As can be seen, there are 27 treatment combinations in this design.

Table 3: Orthogonal fractional factorial design with eight attributes and three levels

	A	B	C	D	E	F	G	H
1	0	0	0	0	0	0	0	0
2	0	0	1	1	1	2	1	2
3	0	0	2	2	2	1	2	1
4	0	1	0	0	1	1	2	2
5	0	1	1	1	2	0	0	1
6	0	1	2	2	0	2	1	0
7	0	2	0	0	2	2	1	1
8	0	2	1	1	0	1	2	0
9	0	2	2	2	1	0	0	2
10	1	0	0	1	1	1	1	1
11	1	0	1	2	2	0	2	0
12	1	0	2	0	0	2	0	2
13	1	1	0	1	2	2	0	0
14	1	1	1	2	0	1	1	2
15	1	1	2	0	1	0	2	1
16	1	2	0	1	0	0	2	2
17	1	2	1	2	1	2	0	1
18	1	2	2	0	2	1	1	0
19	2	0	0	2	2	2	2	2
20	2	0	1	0	0	1	0	1
21	2	0	2	1	1	0	1	0
22	2	1	0	2	0	0	1	1
23	2	1	1	0	1	2	2	0
24	2	1	2	1	2	1	0	2
25	2	2	0	2	1	1	0	0
26	2	2	1	0	2	0	1	2
27	2	2	2	1	0	2	2	1

3.3.5. Choice set generation

Since this research focuses on a main effects design, the step of attribute allocation for interaction effects is not further elaborated in this report and the next step is then to attach the attributes and levels to the design codes in table 3. In other words, the coding is translated into a choice set with interpretable alternatives existing in the hypothetical scenarios. Every treatment combination forms an alternative to be evaluated in the stated choice experiment. However the design as in table 3 is fixed, the 'meaning' of the codes can be defined by the analyst. As can be seen in table 3, the first row of treatment combinations will lead to a dominant alternative when the most positive attribute level is assigned to the code '0'. Hence, the attribute levels are assigned differently to the design codes in order to mitigate the existence of extremely dominant alternatives. Besides avoiding the existence of dominant alternatives, the rule was set to avoid alternatives in which 'three priority intersections', 'three non-priority intersections' and 'three traffic lights' existed on the specific route. By shifting the attributes on the columns and the coding for the levels in such way, these unrealistic dominant attributes have been excluded from the choice set. Table 4 shows which attribute levels have been assigned to which design code for the route-choice experiment and table 5 shows the same for the mode-choice experiment. The tables furthermore show to which column of table 3 the attributes are assigned. Appendix D shows the full 27 treatment combinations for both experiments with the attributes and levels assigned to the rows and columns of table 3. Furthermore, a score is added to Appendix D where the negative attribute levels score 0 and the positive levels score 2, hence for each profile a scoring on a scale from 0 to 16 is applicable where 16 is the most positive combination. This way, dominance can be observed amongst treatment combinations.

Table 4: Design coding translated into attributes and levels for the route-choice experiment

Column	Attribute \ Design Code	0	1	2
F	Travel Time	15 Minutes	19 Minutes	17 Minutes
B	Bicycle Facility Type	Bicycle Path	No Facility	Bicycle Lane
G	Traffic Speed	50 km/h	60 km/h	30 km/h
C	Non Priority Intersections	Three Intersections	One Intersection	No Intersections
A	Priority Intersections	No Intersections	One Intersection	Three Intersections
D	Traffic Lights	Three Intersections	One Intersection	No Intersections
H	Slope	No Slope	One Slope	Two Slopes
E	Pavement Quality	Medium Quality	Low Quality	High Quality

Table 5: Design coding translated into attributes and levels for the mode-choice experiment

Column	Attribute \ Design Code	0	1	2
A	Bicycle Travel Time	15 Minutes	17 Minutes	19 Minutes
B	Bicycle Parking	Secured Facility	No Facility	Non Secured Facility
C	Route-Comfort	*	***	*****
D	Car Travel Time	-0% Minutes	-20% Minutes	-40% Minutes
E	Car Delay	+10% Minutes	+20% Minutes	+0% Minutes
F	Car Parking	Secured Facility	No Facility	Non Secured Facility
G	Public Transport Travel Time	+/- 0% Minutes	+20% Minutes	-20% Minutes
H	Public Transport Delay	+0% Minutes	+10% Minutes	+20% Minutes

3.3.6. Choice set randomization

Appendix D shows all treatment combinations which will be used in the experiments. Due to a certain learning curve of the respondents, presenting the choice sets in the same order every time might lead to biased results. The respondent might need a couple of examples first to get used to the choice tasks. Therefore, the reasoning behind the made choices will for the first couple of combinations not likely be the same as for later made choices (Hensher et al., 2005). In order to prevent and exclude these order biases, randomization of choice sets is applied.

Online surveys, filled in on a computer allow randomization more easily while overcoming data entry problems. For this research, an online questionnaire has also been used to gather the data. For the route-choice experiment consisting of two alternatives to choose from per task, the 27 profiles as defined in Appendix D have been randomized nine times. This way, 243 random alternative combinations were made. Hence, 27 respondents can take part in a unique choice-experiment of nine choice tasks to prevent order biases. For the mode-choice experiment, there are 27 unique profiles defined as in Appendix D. These will be randomly shuffled to provide different ordered choice sets to the respondents.

3.3.7. Survey construction

The last stage as mentioned by Hensher et al. (2005) is the construction of a survey instrument. The instrument should be appropriate for the study objective and should therefore not include any unimportant questions. Besides the question of 'what' to ask, there is the great question of 'how' to ask a certain question to the respondent. The respondent needs to have a good understanding of the question and should be able to interpret the research objective in the right way. As mentioned in section 3.4.2., ambiguity should also be avoided. Hence, being specific in describing the questionnaire is important.

As with being specific in questioning the respondent, it is at first of major importance to define the decision context. Therefore in the online questionnaire, the respondent is provided with a comprehensive explanation before the start of each part. The questionnaire which is created for this research consists of four parts, which will be explained in further detail below: Questions regarding habit and behavior; Route-choice behavior; Mode-choice behavior; and Socio-demographic factors.

The first part of the questionnaire concerning habit and behavior of the respondents includes revealed preference questions for the stated preference part, later in the survey. The first question is about the most frequent used **'Bicycle Type'**, where a distinction is made between a standard bicycle (including racing bicycles and mountain bikes) and an E-Bike (including the speed pedelec). The respondent can also choose the option that he or she never cycles. If the latter is chosen, the respondent is screened out of the questionnaire.

During the 'habit and behavior' part of the questionnaire, the respondents are linked to either a standard bicycle or E-Bike, short or long distance questionnaire and to a commute or recreational trip purpose, based on their answers. Respondents are also asked to what extent they agree with some **'Behavioral statements'** and their **'Motives to cycle'**. A hypothesis is that the respondents' decisions in the choice experiment are related to the answers in the revealed preference part. One who often negates red lights for instance, will probably feel less travel resistance of a traffic light on the route than someone who always waits for red lights.

The second part of the questionnaire introduces the **'Route-choice experiment'**, where an explanation is given of the incorporated attributes as defined in section 3.4.2.. Here, example images are used to create the right decision context for the respondent being as specific as possible. The respondent has to make nine route-choice decisions, choosing between two alternatives in each task.

The third part of the questionnaire is also a stated preference experiment, introducing the **'Mode-choice experiment'** to the respondent. First, the mode-choice attributes are explained again, as defined in section 3.4.2.. Thereafter, the respondent is asked to choose between the normal bicycle / E-Bike (dependent on the revealed preference data), the car or public transport, given the attributes and levels of the choice set.

The last part consists of personal data of the respondents. Here the respondent's **'Age', 'Gender', 'Household composition', 'Education level', 'Income'** and **'Zip Code'** are asked. The respondents are also asked whether they live in a **'Rural or urban area'**. There is also a possibility to leave a comment about the research afterwards.

3.4. Data Collection and Processing

After the development of the choice experiment, the data collection and processing procedures should be considered. The quality of the research and the results strongly depends on the data collection process. A distinction into different segments in the research was already made in section 3.4.1., i.e. standard bicycle use, E-bike use, long distance trips and short distance trips and commuting or recreational purposes. The importance of providing a realistic decision context to the respondent has also been explained before. As mentioned, people who never cycle are screened out of the survey and will not further take part in the research. Further explanation of the required respondents' characteristics and the number of respondents are provided in the following sub-sections.

3.4.1. Sampling procedures

The research is focused on the 'occasional-', 'regular-' and 'utility cyclists', hence the respondents are selected on these characteristics. The data collection and gathering of respondents was outsourced to a certified online panel service (PanelClix). Since the results of the research have to be applicable to the general population of the Netherlands, the panel service was asked to gather data with a distribution of social economic classes comparable to the Netherlands.

There is no absolute measure available to determine the required number of respondents for the research on forehand (Hensher et al., 2015). Though an assumption can be made of the required number of respondents. Since there are 27 tasks in the research, it is assumed that a total number of 1080 observations is required as an absolute minimum for the research. If each respondent would only have to complete one choice task, the number of respondents would be quite high, hence the respondents are asked to complete nine choice tasks in the experiment. With each respondent completing nine choice tasks of the 27 choice tasks which require in total 1080 observations, the minimum number of respondents for the research is estimated to be 120. Since the research is divided into four segments, two long and short distance classes for normal bike and e-bike usage, it can be stated that for each segment 120 respondents need to complete nine choice tasks. Hence, a total of 480 respondents is required for all segments of the research. Due to the complexity of the choice tasks, the further distinction of trip purposes within the choice experiments, a total number of around 750 respondents will be approached by the online panel service.

Hensher et al. (2005) mention the importance of testing the questionnaire before conducting the full research. The online questionnaire for this research was also pre-tested. The online questionnaire was completed by 52 respondents who were asked to leave feedback at the end of the survey. The test showed that the online questionnaire was correctly being translated to a useful data output. The 52 respondents consisted of experts in the field of transport modelling as well as respondents who are not familiar with the field of transportation research. Most of the respondents included feedback at the end of the questionnaire of which as most as possible has been processed for the final questionnaire. The feedback has been used to improve the questionnaire. Furthermore, many respondents filled in the questionnaire for short distance trips, hence the routing within the online questionnaire had been adjusted to get more response for the long distance trips.

3.4.2. Data processing

When the required data is collected, the data processing can start. The online filled in questionnaires will be exported to a format which is readable for SPSS software. Although the process of preparing the data set is often not extensively described in many researches, it is of major importance to carefully approach the data set before starting the full analysis.

At first, the data will be checked on the following aspects: Whether the questionnaires are completely filled in, whether the completion time is acceptable and if there is some variance in the answering. Unacceptable questionnaires will be eliminated in the analysis in order to improve the validity of the results.

Besides eliminating the unacceptable answers, the data will also be checked on other extreme values, inconsistencies and out-of-range answers. The choice experiments will be analyzed using NLogit software. Hence, transcribing the data set for compatibility with this software package is also necessary. In order to prepare the choice sets in the experiment for analysis, effect coding will be used.

After checking and cleaning the data set, the analysis of descriptive statistics will be executed to get an overview of the respondents' characteristics and the distributions. A comparison to the distribution of the population of the Netherlands will be made as a reference to the distribution of the sample population. Thereafter the model analysis can take place, where the relationship between the dependent variable choice and the independent variables, being the choice set characteristics, will be analyzed.

3.5. Conclusion

This chapter gave an extensive overview of the steps to be taken in the research process. Not all steps are covered to such an extent in available literature, though the importance of carefully considering each step should not be underestimated. This chapter started with an elaboration on the stated preference method and why this is preferred over other methods, such as revealed preference. Since the purpose of this research is to gain more insight in assessing the potential and effectiveness of new cycling routes, stated preference has more advantages due to the possibility to create fictive decision contexts. Stated preference is already widely being applied in transportation studies. Hence, common pitfalls in its application are also known.

In this research two choice tasks have been defined: a route-choice task and a mode-choice task. Both tasks are coupled by means of a comfort evaluation task. Hence, three model analyses have to be applied in the next section. Much time and effort has been assigned to creating the choice experiments, since the respondents are easily biased by visualizations or become exhausted by too much text. The questionnaire has been pre-tested under 52 respondents. The feedback on the pilot questionnaire proved to be very useful for improving the questions and decision context. The results of the final questionnaire will be analyzed in the next chapter.

4. RESULTS

4.1. Introduction

After the online questionnaire has been spread among the respondents, the analyses can be executed. In the following section, the descriptive statistics will be presented, which were achieved using IBM SPSS Statistics 23 software. Once the data set has been processed as described in section 3.5.2., the data can be used for further analyses. The model analyses consists of three parts. First the route-choice parameters will be estimated, thereafter an ordinal and multinomial logistic regression will be used to find the relation between the route aspects and the valuation of route comfort and finally the mode-choice parameters are estimated.

4.2. Descriptive Analysis

The first step in the data processing process, was to filter out the incomplete questionnaires. From the online panel, a dataset of 853 filled in questionnaires was obtained. From this dataset 63 filled in questionnaires were removed due to incomplete data. Hence 790 completely filled in questionnaires remained in the dataset. Since hardly any questions were asked using an open answer field, no extreme values or out of range answers could be given by the respondents. Besides the provided answers, the completion time of the questionnaires also gives an impression of the validity of the results. The completion time of the filled in questionnaires did show some variation, though the mean of the completion time was around 16 minutes and the mode of the completion time was 11 minutes. There were 62 respondents who completed the questionnaires in less than 6 minutes. For this questionnaire, the validity of these results was doubted and were hence deleted from the dataset. The dataset which has been cleaned and prepared for further analysis contained 728 completely filled in questionnaires.

4.2.1. Respondents' characteristics

The last part of the questionnaire contained questions about the respondents' personal characteristics. The first part of the questionnaire was used to gather more information on the preferences and behavior of the respondents. To get an overview of the respondents' characteristics, the descriptive statistics will be presented in this section. The sample population's characteristics will be compared to the general population of the Netherlands as published online by the Central Bureau of Statistics (CBS) to have some reference of how the distributions are compared to each other and due to the lack of other data for comparison.

Figure 6 shows that the respondents are located all over the Netherlands, where most respondents live in the province of Zuid-Holland and the least respondents come from the province of Flevoland. This corresponds to the number of citizens in the Dutch provinces, although Utrecht is slightly underrepresented.

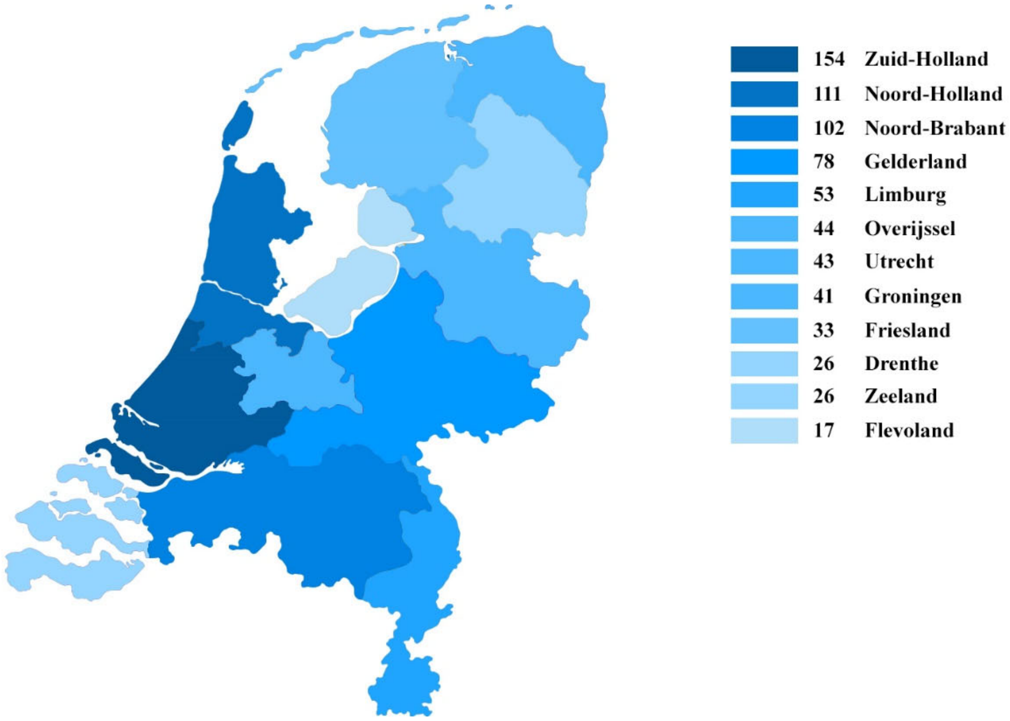


Figure 6: Respondents' origins distributed over The Netherlands

Table 6 shows the respondents' gender and the distribution of the overall population of the Netherlands' gender. The table shows that an almost even amount of males and females are present in the research, which is also comparable to the distribution in the Netherlands.

Table 6: Sample population's gender and the distribution of the general population according to CBS (2015)

Gender	Sample Frequency	Sample Percentage	General Population
Male	357	49.0%	49.5%
Female	371	51.0%	50.5%

Table 7 shows the respondents' age compared to the distribution of age of the Dutch population. Due to the fact that the respondents have been recruited on an age of 18 years and older, the age class of 16-20 years old is relatively small. Besides that, the age class of 36 – 50 years old seems underrepresented.

Table 7: Sample population's age distribution

Age (Sample)	Sample Frequency	Sample Percentage	Age (CBS, 2015)	General Population
16 – 20 years old	18	2.5%	0 – 20 years old	22.7%
21 – 35 years old	194	26.6%	20 – 40 years old	24.5%
36 – 50 years old	186	25.5%	40 – 65 years old	35.1%
51 – 65 years old	214	29.4%	65 – 80 years old	13.4 %
66+ years old	116	15.9%	80+ years old	4.3%

Table 8 shows the respondents' education level compared to the general population of the Netherlands. The table shows a low presence of respondents who are only lower educated. This might also be because of the selection on age of 18 years and older. The distribution shows a high presence of higher vocational educated people.

Table 8: Sample population's education and the distribution of the general population according to CBS (2015)

Education Level	Sample Frequency	Sample Percentage	General Population
Lower Education	17	2.3%	10.7%
Secondary Eduation	122	16.8%	21.5%
Vocational Education	300	41.2%	39.1%
Higher Vocational Education	229	31.5%	17.7%
University Education	58	8.0%	9.9%
Other, Unknown	2	0.3%	1.1%

Table 9 shows the diverse household compositions of the respondents. Most of the respondents are living with their partner, without children.

Table 9: Household compositions of the sample and the general population CBS (2015)

Household Composition	Sample Frequency	Sample Percentage	General Population
Single Household	145	19.9%	37.4%
Living with Parents	51	7.0%	n.a.
Single Parent with Child(ren)	33	4.5%	7.1%
With Partner without Child(ren)	314	43.1%	29.0%
With Partner with Child(ren)	185	25.4%	26.5%

The final descriptive statistics show the income classes of the respondents' households in table 10. The lower income classes are underrepresented in the results. The income class of €30,000 – €40,000,- is slightly overrepresented.

Table 10: Net annual income per household of the sample and the general population CBS (2015)

Net Annual Income / Household	Sample Frequency	Sample Percentage	General Population
Till €10,000,-	27	3.7%	5.9%
€10,000 - €20,000,-	85	11.7%	22.6%
€20,000 - €30,000,-	133	18.3%	24.7%
€30,000 - €40,000,-	154	21.2%	17.7%
€40,000 – €50,000,-	84	11.5%	12.2%
€50,000,- +	100	13.7%	16.9%
Unknown	145	19.9%	0%

It can be stated that the dataset shows similarities compared to the Dutch population. More research should be conducted to investigate whether this is a proper reference. Since the respondents were screened out of the research if they never made use of the bicycle, actual cycling travel data would be a better reference. Although some sub-groups are underrepresented compared to the Netherlands in general, it can be stated that of all sub-groups respondents are present in the sample. Hence, the data is considered as a useful data source to continue the further analyses with.

4.2.2. Respondents' habits and behavior

During the first part of the questionnaire, the respondents were asked several questions regarding their current behavior and habits. As already explained in section 3.4.1., the questionnaire was divided into four different sub-questionnaires. Table 11 shows that 626 respondents completed the questionnaire for the standard bicycle type and only 102 respondents completed the questionnaire for the E-Bike. Overall, a total of 321 respondents filled in the short-distance questionnaire, and 407 filled in the questionnaire for longer distance trips.

As was expected can be stated the E-Bike is mainly used for longer distances, while the standard bicycle is also often used for shorter distances. Within these four sub-questionnaires, there was also a distinction made in trip purposes, i.e. commuting and other recreational purposes.

Table 11: Distribution of the respondents among the sub-questionnaires

	Standard Bicycle		E-Bike		
	Commuting	**Other Recreational**	**Commuting**	**Other Recreational**	*Total*
Short Distance	123	173	4	21	321
Long Distance	214	116	39	38	407
Total	337	289	43	59	728
	626		102		

The distribution of respondents as shown in table 11 is based on the answers in the first part of the questionnaire. These answers are summarized in figure 7. Figure 7 shows the cycled distances per bicycle type and per trip purpose. This figure also shows that the E-Bike is more often used for longer distances than the standard bicycle.

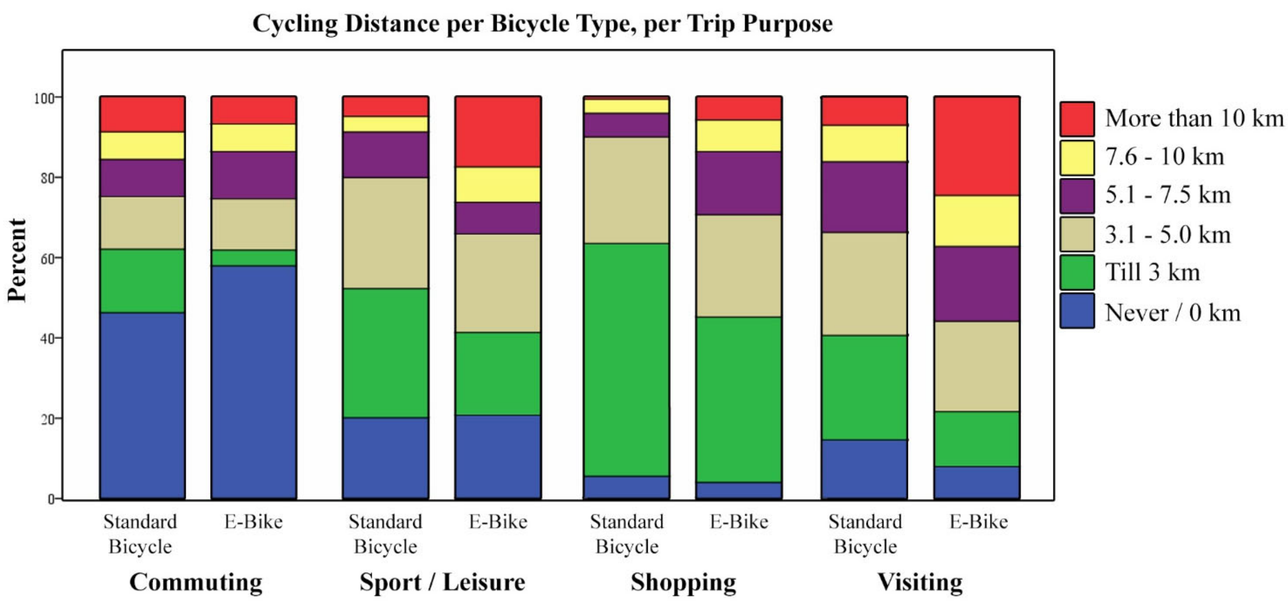


Figure 7: Cycling distance per bicycle type, per trip purpose

As mentioned in section 2.2.1, the mode-choice is influenced by the trip purpose. Heinen, van Wee and Maat (2010) stated adding cycling frequency as important. Figure 8 shows the frequency of bicycle, car and public transport use for different trip purposes. Public transport is the least frequent used mode. The car and bicycle seem to be competitive modes for several trip purposes, even for shopping.

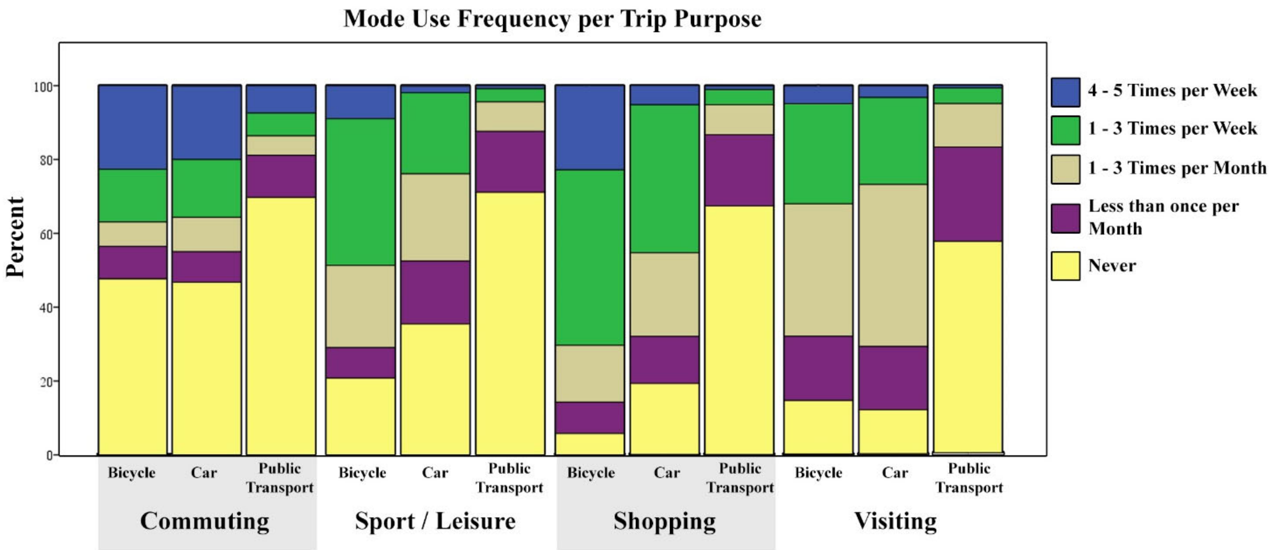


Figure 8: Mode use frequency per trip purpose

During the mode-choice experiment later on in the questionnaire, the respondents were provided the case in which they can always choose between the bicycle, car or public transport. In the first part of the questionnaire, 9.5% of the respondents answered to have no car available at any time and 67.7% answered always having a car available and 22.8% sometimes has a car available, hence stating the availability of all three previous mentioned modes during the experiment does not seem very unrealistic.

Finally the respondents were asked to what extent the motives as shown in table 12 are influential on the decision to cycle or not. The results are presented from most to least influential in table 12. Furthermore, the respondents could provide another motive in the open answer field. 12 respondents mentioned to choose for the bicycle because it is faster. 19 others mentioned to like cycling as a recreational exercise taking place outside. Other mentioned motives were: Parking, the weather, car availability, drinking alcohol and short trip distance.

Table 12: Motives to cycle

Motives	Does influences	Neutral	Does Not Influence	No Opinion
Health Benefit	74.7%	20.2%	4.8%	0.3%
Ease of Use	47.8%	36.1%	15.2%	0.8%
Financial Benefit	46.2%	28.3%	24.7%	0.8%
The Environment	42.3%	36.1%	20.3%	1.2%
No Driving License	15.7%	1.6%	81.6%	1.1%
Fear of Driving	4.0%	7.0%	86.3%	2.7%

Regarding the route-choice behavior, several statements were provided to the respondents. The full results of these statements are presented in Appendix F. Of all respondents, 72% agreed on never running red lights and 65.9% agreed on the statement of never cycling in the wrong direction. Although Sener et al. (2013) found that parked cars influenced route-choice decisions, it did not seem to influence the route-choice to a large extent here, since 68% disagreed on adjusting their route because of parked cars. The opinions are also diverse regarding avoiding unsafe routes. This might be because of the different interpretations of 'unsafe'. Although cycling with kids was not applicable to many respondents, still 45.1% agreed on adjusting their route when cycling with children, which was also concluded as influential by Dill & Gliebe (2008). Milakis & Athanasopoulos (2014) found the scenery as influential. This does also count for this research, since 66.9% of the respondents agreed on adjusting their route for a better scenery. In the next section, the route-choice attributes are further analyzed.

4.3. Model Analysis

In this section, the route- and mode-choice attribute parameters are estimated using Limdep NLogit 5 software. First, a model will be estimated including only the main effects. Thereafter some significant interaction effects will be introduced to the model. For the valuation of the route-comfort, both an ordinal and multinomial logistic regression are conducted in IBM SPSS Statistics 23 software to find the relation between the route-choice attribute levels and the perception of comfort. Finally the mode-choice attribute parameters will be estimated, again using Limdep NLogit 5 software.

Before conducting the model analysis, the dataset had to be transcribed to another format in which each choice alternative is represented as one row in the dataset. Besides that, the design coding of the attribute levels as described in section 3.4.6. has been recoded using effect coding as shown in table 13. For further reading on dataset preparation, the reader is referred to Hensher et al. (2015).

Table 13: Effect coding of the three-level attributes

Level \ Design Code	X1	X2
0	1	0
1	0	1
2	-1	-1

4.3.1. Route-choice attributes

The first model to be estimated is the route-choice model. A basic multinomial logit model (MNL), including only the main effects is estimated to start with. The NLogit output of the MNL route-choice model is added to Appendix G. The parameter estimates for the attribute levels are shown in table 14. As can be seen, the priority intersections did not have a significant influence on the choice variable. The presence of one slope on the route did neither turn out to have a significant effect on the route-choice. All other attribute levels were significant ($p < 0.05$). Note that the attribute 'travel time' is recoded into two separate attributes for long and short distance trips. Table 14 shows the utilities of the attribute levels on the choice variable, the range of the lowest and the highest level and the significance of the utility estimates. Note that the base level is not always the same level. This was done to prevent dominance in the choice set, as explained in section 3.4.5.. Additional to table 14, the utilities are also presented as charts in Appendix H.

Table 14: Importance of route-choice attributes

Attribute	*Level*	*β*	*Sign.*	*Range*
	15 minutes	0.42402	0.0000	
Travel Time Short	17 minutes	0.00742	-	0.85546
	19 minutes	-0.43144	0.0000	
	25 minutes	0.19605	0.0000	
Travel Time Long	27 minutes	-0.00742	-	0.38419
	29 minutes	-0.18814	0.0000	
	Bicycle Path	0.74189	0.0000	
Bicycle Facility	Bicycle Lane	0.14432	-	1.6281
	No Facility	-0.88621	0.0000	
	30 km/h	0.29371	-	
Traffic Speed	50 km/h	-0.09235	0.0015	0.49507
	60 km/h	-0.20136	0.0000	
	High Quality	0.63046	-	
Pavement Quality	Medium Quality	0.09789	0.0007	1.35881
	Low Quality	-0.72835	0.0000	
	No Intersections	0.03748	0.2202	
Priority Intersections	One Intersection	-0.00925	0.7514	0.06571
	Three Intersections	-0.02823	-	
	No Intersections	0.35025	-	
Non-Priority Intersections	One Intersection	-0.07394	0.0126	0.62656
	Three Intersections	-0.27631	0.0000	
	No Intersections	0.15195	-	
Traffic Lights	One Intersection	0.06868	0.0161	0.37258
	Three Intersections	-0.22063	0.0000	
	No Slopes	0.47309	0.0000	
Slope	One Slope	0.02821	0.3684	0.97439
	Two Slopes	-0.5013	-	

The output in Appendix G shows that the model used 6552 observations, since there are 9 observations for all 728 respondents. When looking at the log likelihood of the null-model and the optimal model, it can be seen that the optimal model performs better than the null model. The null model has a log likelihood of -4541.5003. The optimal model as presented in Appendix G has a log likelihood of -3390.4894, which is better since its value is closer to zero. With equation (8) as described in section 3.3.1., the rho-squared or likelihood ratio index can be calculated. Using the values of the null-model and the optimal model as explained above, the rho-squared is 0.2534. Although the value of the likelihood ratio statistic can range from zero to one, with one as the best fit, a value of 0.25 is still seen as a good model fit (Ortúzar & Willumsen, 2011). Besides the 'normal' rho-squared, there is also an adjusted rho-squared calculated by subtracting the 18 degrees of freedom from the optimal model (Hensher et al., 2015). The adjusted rho-squared has a slightly lower value of 0.2514.

Another statistic to define the model performance is the chi-squared test, or the likelihood ratio test, which is calculated by subtracting the log likelihood of the optimal model from the log likelihood of the null model, multiplied by -2. Executing the latter, gives a value of

2302.021. Since there are 18 degrees of freedom, a critical upper-tail value of the chi-squared distribution according to chi-squared tables for 18 degrees of freedom and a confidence of 99.9% is 42.312. Since the value of 2302.021 clearly exceeds the value of 43.312, the hypothesis that the optimal model does not perform better than the null model is being rejected.

During the literature review in chapter 2, there was already stated that more attributes are of important influence than only travel time. Stinson and Bhat (2003) for instance, found that travel time reduction was the most important attribute, but added that separate paths, smooth pavement and less crossings were preferred. Figure 9 shows the ranges as defined in table 14 from most to least important. Note that a difference is observed for longer and shorter distance travel time reductions. Dill and Gliebe (2008) also concluded that facility type was an important preference besides the shortest path and Yang and Mesbah (2013) found the gradient of the route influential. Figure 9 confirms the influence of slopes on the route. Menghini et al. (2010) did also find that cyclists tend to avoid stop signs. The importance of avoiding non-priority intersections is also confirmed in figure 9. Priority intersections turned out to be insignificant towards the route-choice.

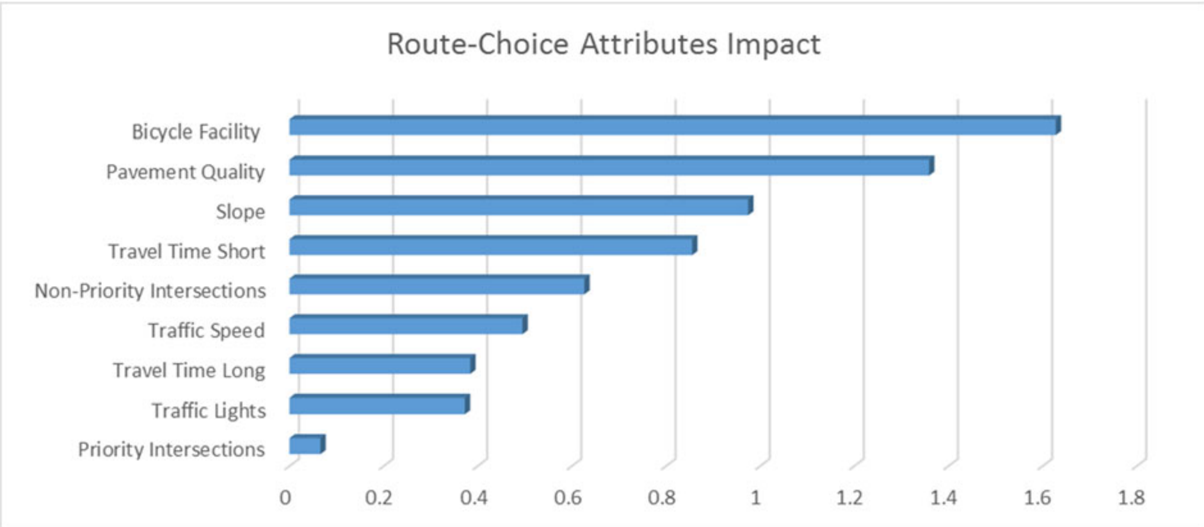


Figure 9: Impact of the route-choice attributes from most to least important

Now that the main effects of the route-choice attributes are estimated, it is of interest to find significant differences between several sub groups within the sample population. As mentioned, the questionnaire made a distinction between standard cyclists and E-Bike users and between short and long distance cyclists. Besides that, the distinction was made between commuting and other recreational trip purposes. Finally the respondents were also burdened with questions about their personal situation. Regarding route-choice as described in the literature review in chapter 2, the most common used demographic attributes are age and gender. Hence, also these two attributes were investigated whether interacting or not with the route-choice attributes. The attribute age has been merged to only two levels, younger than 36 years old and 36 years or older. The NLogit output of the interaction model is added to Appendix I. Only the significant interaction effects were included in the final model. Appendix J shows the utility graphs of the significant interaction effects per attribute level. Figure 10 shows the impact of the route choice attributes in the same order as table 14, taking interactions into account. Note that the inclusion of interactions did also affect some main effects in the final model.

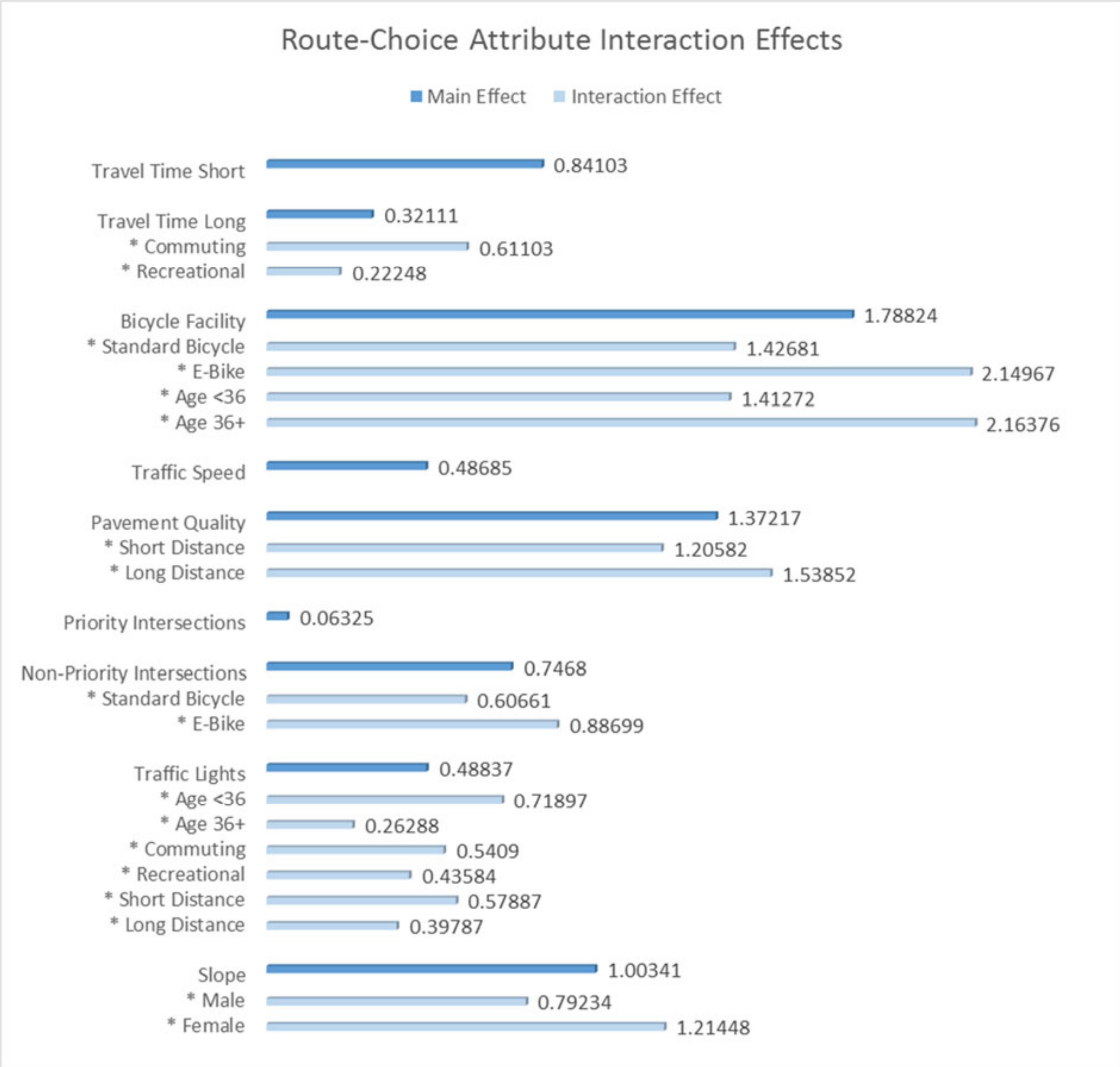


Figure 10: Route-choice attributes with interaction effects

The first significant interaction effect was found for long travel times and trip purposes. Figure 10 shows that recreational cyclists add less value (0.2225) to a 4 minute increase or decrease of travel time than commuting cyclists (0.6110) do on the longer distances. A significant difference regarding bicycle types was found for the valuation of a proper bicycle facility. As can be seen, E-Bike users are more affected by the presence or lack of a proper cycling facility. As the utility graph in Appendix J shows, E-Bike users have a stronger utility and disutility for respectively a separate bicycle path or no cycling facility than standard bicycle users. Standard cyclists value the presence of a bicycle lane higher than E-Bike users. For age, there were also differences found regarding the valuation of a cycling facility. People of an age older than 36 are more vulnerable for the lack of a proper cycling facility. Stinson and Bhat (2003) also found that ‘older’ people are more sensitive towards a higher cycling comfort and separate facilities.

As was also expected, a difference regarding the valuation of a smooth pavement was found for short and long distance trips.

E-Bike users seem to feel more impact by the presence of non-priority intersections. Figure 10 also shows that several significant interactions were found for the valuation of traffic lights on the route. First of all can be stated that younger people feel more impact by the presence of traffic lights. This was not expected, since another quick observation at the data showed that of the age class below 36 years old, 38% disagreed on 'never running red lights' during the questionnaire, while within the age class of 36 years and older, 22% disagreed on this statement. Hence, it would be expected that younger people feel less resistance from a traffic light. On the other hand, it might also be conceivable that the older age class experience more safety from the presence of traffic lights and are hence less bothered by the presence of these intersections. The presence of traffic lights had also more effect on commuting cyclists than on more recreational trips. Also on short distances the presence of traffic lights has more impact than on long distances. This was as expected, since the same amount of stops on a longer trip distance results in a lower intersection density. Finally an interaction effect was found for different genders. Females seem to experience more impact from the presence of slopes on the route than males. Dill and Gliebe (2008) did also confirm that women tend to avoid hills more often than men and found that women are more willing to minimize their trip distance and avoid streets with lots of traffic.

When looking at the interaction effects model's performance, the rho-squared shows an increased value of 0.2725 and a rho-squared adjusted of 0.2684. Hence, the model including the interaction effects performs better than the main effects-only model with a rho-squared of 0.25. Likewise as for the main-effects model, the likelihood ratio test can be performed. The log likelihood of the null model with interaction effects remained the same as the main effects only model, i.e. -4541.5003 due to the fact that the increased number of variables has no effect on the value of the null model. The number of degrees of freedom however, has changed to 36 by the addition of interaction effects. The optimal model with interaction effects has a log likelihood value of -3304.1655, resulting in an LRS value of 2474.6696. The value for 36 degrees of freedom with a confidence interval of 99.9% according to chi-squared tables is 67.985. Since, the value of the LRS still exceeds the value obtained from the chi-squared table it can be stated that the model with interaction effects is an improvement to the null model.

4.3.2. Route-comfort valuation

During the route-choice experiment the respondents had to make a choice based on the route-choice attributes as analyzed in previous section. Besides that, they were asked to assess the comfort of both route alternatives on a five-star scale. Two analyses were conducted using IBM SPSS Statistics 23 software to find the relation between the comfort attributes and the valuation of comfort by the respondent. First, the comfort attribute is treated as an ordinal variable, suggesting the five levels have intrinsic value to the respondent on an ordered measurement scale. Second, a multinomial logistic regression is used in combination with several interaction effects to improve the model fit and for more accuracy of the model.

4.3.2.1. Ordinal regression

The SPSS output of the ordinal regression is added to Appendix K. The case processing in Appendix K confirms that each attribute level is represented in an equal amount of times to the respondents and that a three-star valuation is most often selected as the level of comfort by the respondents. The model fitting information shows that the model performs better than the intercept only model. Since the model fitting is significant ($p < 0.05$), the null hypothesis that the model without predictors is as good as the model with predictors is being rejected. The goodness-of-fit does not represent such a good fit for the data. Since the Pearson and Deviance show significant values, the hypothesis that the model fits the data well, is being rejected. This means that the model's predicted values do not fit the observed values very well. When looking at the Pseudo R-Square box in the SPSS output, one could observe that the McFadden R-Square has a low value of 0.093 which also assumes that the model does not predict the data very well. Though when looking at the Nagelkerke statistic, which is an adjustment to the Cox and Snell statistic and allows values between zero and one, a value of 0.248 is found. This is considered as a modest model fit for the data.

Table 15: Route-comfort coefficients using ordinal regression

Threshold	*Level*	*β*	*Sign.*
Comfort	*/**	-3.553	0.000
	/*	-1.597	0.000
	/*	0.311	0.000
	****/*****	2.312	0.000
Attribute	Level	β	Sign.
Bicycle Facility	Bicycle Path	0.576	0.000
	Bicycle Lane	0	-
	No Facility	-0.870	0.000
Traffic Speed	30 km/h	0	-
	50 km/h	-0.405	0.000
	60 km/h	-0.447	0.000
Pavement Quality	High Quality	0	-
	Medium Quality	-0.885	0.000
	Low Quality	-1.845	0.000
Priority Intersections	No Intersections	0.061	0.119
	One Intersection	0.126	0.001
	Three Intersections	0	-
Non-Priority Intersections	No Intersections	0	-
	One Intersection	-0.165	0.000
	Three Intersections	-0.332	0.000
Traffic Lights	No Intersections	0	-
	One Intersection	-0.210	0.000
	Three Intersections	-0.231	0.000
Slope	No Slopes	0.647	0.000
	One Slope	0.408	0.000
	Two Slopes	0	-

The parameter estimates box shows that the thresholds of the comfort levels are evenly distributed. Table 15 shows the coefficients of the attribute levels which influence the assigned comfort level to the specific route alternative. The larger the value of the coefficient, the higher the probability of receiving a higher comfort rating. Only the absence of a priority intersection turned out to be insignificant at the 90% confidence interval. Remarkable, is that the presence of a priority intersection is slightly more likely to receive a higher comfort rating than the absence of a priority intersection. Hence, the presence of a priority intersection might be seen as comfortable. What can be seen is that the pavement quality has the strongest relation with the comfort valuation. Next, the facility type is of major influence on the valuation of route comfort. Then follows the presence of slopes, the speed of other traffic on the roads and the number of non-priority intersections.

Figure 11 shows the ranges of the impact on route-comfort. Note from figure 9 and 10 that for the route-choice decision, the presence of a proper bicycle facility is most important, though for the comfort valuation the pavement quality is most important.

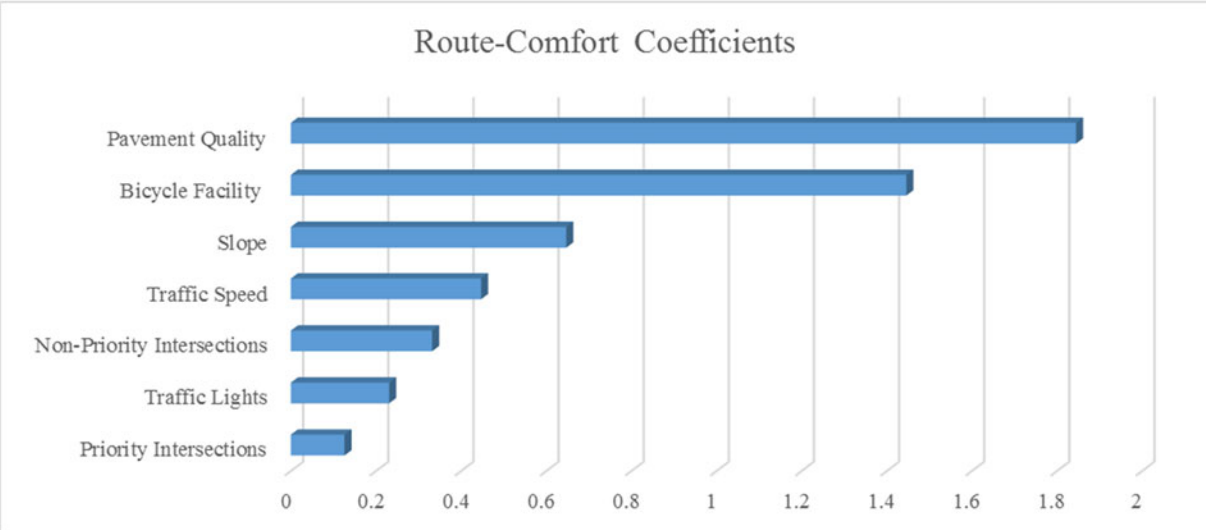


Figure 11: Route-comfort attributes from most to least important

Adding interaction effects to the ordinal regression model did not result in higher values for the Pearson and Deviance statistics. Hence, the use of multinomial logistic regression might be a better method to apply.

4.3.2.2. Multinomial logistic regression

For the multinomial logistic regression, the backward stepwise estimation method was used for model estimation. Insignificant interaction effects were removed by SPSS. Part of the SPSS output of the multinomial logistic regression is added to appendix L. The priority intersections attribute was also removed from the analysis due to insignificance. First of all, the model fitting information showed that the model is a significant improvement to the intercept only model, since the likelihood ratio test is significant. When considering the Pseudo R-Square values, a Nagelkerke statistic of 0.267 is found and a McFadden R-Square of 0.102. These values are only slightly better than the ordinal regression's model performance. Though when looking at the Goodness-of-Fit, the Pearson has a significance of 0.685 and the Deviance has a significance value of 0.140. Hence, the hypothesis that the model fits the data well is not being rejected for this multinomial logistic regression model, meaning an acceptable model fit.

Instead of estimating a single coefficient for each attribute level and all comfort levels as in the ordinal regression model, the multinomial logistic regression model estimated coefficients for the attribute levels and each comfort level separately while holding one level constant. Therefore, the model is more accurate and extensive. Table 16 shows the parameter estimates for each comfort level. Note that the three-star comfort level was taken as the reference category for the analysis. Few parameter estimates did not significantly differ from zero effect. Overall can be stated that the distribution of log odds seems realistic and considering figure 12 on the next page, the range of parameter estimates shows the same order of attribute importance as figure 11 does for the ordinal regression output. Appendix M does also show the interaction effects which were found significant. Long distance cyclists seem to be less sensitive to the comfort valuation of different bicycle facility types. Adding to that, people of an age older than 36 years seem to be more critical towards the lack of a bicycle facility or the presence of a bicycle lane instead of a bicycle path. As can be seen, 'no bicycle facility' has a very high value for the one-star comfort level. Appendix M shows the interactions of only one interaction level, i.e. only long distance, age 36+, etc. The other interaction levels, i.e. short distance, age <36, etc. were set to zero effect by SPSS as shown in Appendix L. Thus the values for the other levels are the same as the main effects. Insignificant values have been treated as zero effect. Now a more specific description of route-comfort is known, the attribute route-comfort can be used for the mode-choice analysis.

Table 16: Route-comfort coefficients using multinomial logistic regression

Attribute	Level	*	**	***	****	*****
Intercept		-2.554	-0.813	0	-0.598	-1.375
Bicycle Facility Type	Bicycle Path	0.081	-0.29	0	0.493	0.487
	Bicycle Lane	0	0	0	0	0
	No Facility	0.972	0.188	0	-0.581	-0.76
Non Priority Intersections	No Intersections	0	0	0	0	0
	One Intersection	0.114	0.191	0	-0.116	-0.108
	Three Intersection	0.239	0.215	0	-0.244	-0.509
Traffic Light Intersections	No Intersections	0	0	0	0	0
	One Intersection	-0.227	0.111	0	0.13	-0.565
	Three Intersection	-0.262	0.032	0	-0.16	-0.517
Pavement Quality	High Quality	0	0	0	0	0
	Medium Quality	0.393	0.31	0	-0.794	-1.281
	Low Quality	0.1736	1.067	0	-1.181	-1.669
Traffic Speed	30 km/h	0	0	0	0	0
	50 km/h	-0.143	0.275	0	0.005	-0.613
	60 km/h	0.019	0.354	0	-0.081	-0.353
Slope	No Slopes	-0.382	-0.497	0	0.626	0.743
	One Slope	-0.347	-0.333	0	0.36	0.651
	Two Slopes	0	0	0	0	0

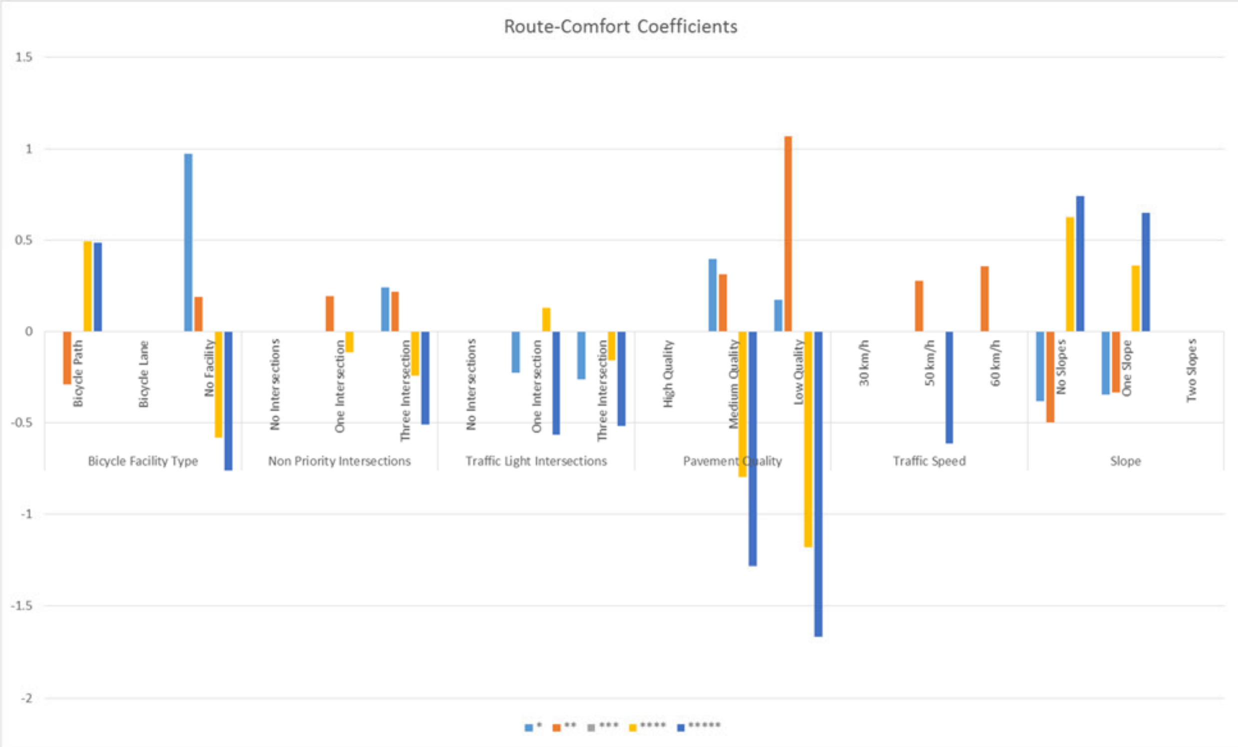


Figure 12: Route-comfort coefficients

4.3.3. Mode-choice attributes

The final model to be estimated is the mode-choice model. A quick observation of the choice variable showed that some respondents did not vary their choice. A quite large number of respondents chose the car (10%) or bicycle (30%) all nine times of the nine choice tasks. In reality there are also stubborn car drivers and utility cyclists, though this did also influence the parameter estimates. The utilities of all mode-choice attributes and levels are presented as charts in Appendix O. Appendix N shows the NLogit output of the basic MNL mode-choice model. The parameter estimates, alternative specific constants and significance levels are shown in table 17 on the next page.

Bicycle travel time for the long distances turned out to have no significant effect on the mode choice. For many other variables, the second attribute level did not significantly influence the mode-choice. This assumes a linear property of the utility function. First of all can be seen that the car and bicycle are preferred over public transport due to the higher value of the alternative specific constant (ASC). The ASC of the bicycle is higher than the car, meaning that for this research the bicycle was preferred over the car. For the bicycle as a mode, travel time seemed to be less important than the route-comfort and parking facility at their destination, whereas for the car the travel time is more important, followed by the availability of a good parking facility.

The NLogit output in Appendix N shows that for the mode-choice MNL model a total of 6552 observations are used, which corresponds to the 728 respondents who completed 9 choice tasks. It took 5 iterations for the model to converge.

Table 17: Importance of mode-choice attributes

Attribute	*Level*	*β*	*Sign.*	*Range*
Alternative Specific Constant	Bicycle	1.77914	0.0000	1.77914
	Car	1.16974	0.0000	
	Public Transport	0	-	
Bicycle Travel Time Short	15 minutes	0.15238	0.0057	0.28532
	17 minutes	-0.01944	0.7269	
	19 minutes	-0.13294	-	
Bicycle Travel Time Long	25 minutes	-0.00744	0.8790	0.10986
	27 minutes	0.05865	0.2345	
	29 minutes	-0.05121	-	
Bicycle Parking Facility	Secured	0.41206	0.0000	0.68971
	Non-Secured	-0.13441	-	
	No Facility	-0.27765	0.0000	
Bicycle Route-Comfort	*****	0.24651	-	0.54539
	***	0.05237	0.1570	
	*	-0.29888	0.0000	
Car Travel Time (Relative to Bicycle Travel Time)	- 40% Minutes	0.48946	-	0.93168
	- 20% Minutes	-0.04724	0.2272	
	- 0% Minutes	-0.44222	0.0000	
Car Delay (Relative to Car Travel Time)	+ 0% Minutes	0.26627	-	0.48517
	+ 10% Minutes	-0.04737	0.2361	
	+ 20% Minutes	-0.21890	0.0000	
Car Parking Facility	Secured	0.37485	0.0000	0.79246
	Non-Secured	0.04276	-	
	No Facility	-0.41761	0.0000	
Public Transport Travel Time (Relative to Bicycle Travel Time)	- 20% Minutes	0.36439	-	0.74922
	+/- 0% Minutes	0.02044	0.7427	
	+ 20% Minutes	-0.38483	0.0000	
Public Transport Delay (Relative to PT Travel Time)	+ 0% Minutes	0.32035	0.0000	0.54098
	+ 10% Minutes	-0.09972	0.1008	
	+ 20% Minutes	-0.22063	-	

When looking at the log-likelihood of the optimal model, the NLogit output shows a value of -5673.3453. In comparison to the constants-only model with a log-likelihood of -6033.2526, the optimal model does only perform slightly better, thus the attributes have not that much influence. For the rho-squared it is of interest to compare the optimal model to the null model. The null model in this case has a lower value of -7198.1077. This gives a rho-squared value of 0.2118 and a rho-squared adjusted value of 0.2106. Again, this can be considered as a good model fit.

When conducting the log-likelihood ratio test by subtracting the log-likelihood of the optimal model from the log-likelihood of the null model, multiplied by -2, a value of 3049.524 is obtained. There are 20 degrees of freedom in the model. Chi-squared tables give a critical upper-tail value of 45.315 for a 99.9% confidence interval. Since 3049.524 exceeds the latter value, the hypothesis that the optimal model does not perform any better than the null model is being rejected.

Figure 13 summarizes the findings from table 17. Akar and Clifton (2010) found that increasing travel times led to a higher decrease in cycling. This is not truly visible in figure 13, probably due to the fact that the respondents who completed the long distance questionnaire are used to cycling longer distances. For the decision to cycle, the most impact comes from the presence of a proper parking facility. The availability of a free secured parking facility increases the propensity to cycle. Van der Waerden and Timmermans (2007) found several infrastructural adjustments influential on the propensity to cycle. Here, a higher route-comfort by means of infrastructural measures also leads to a higher propensity to cycle. For the car, the travel time is most important, followed by the presence of a parking facility. For public transport, the travel time is also most important.

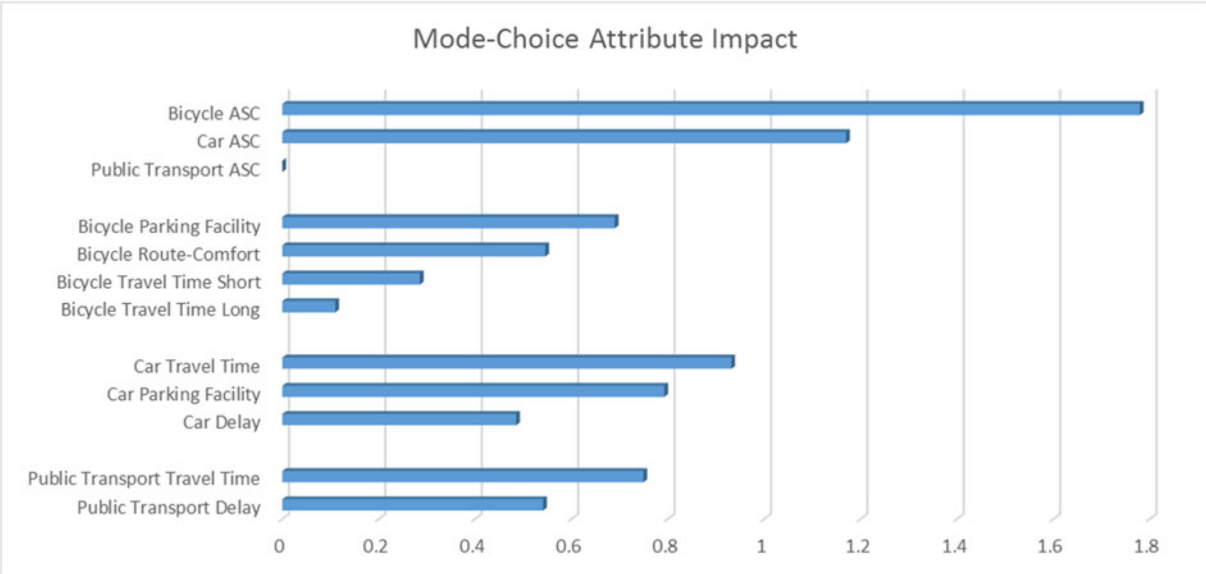


Figure 13: Mode-choice attribute impact

As was investigated for the route-choice experiment, also for the mode-choice experiment was analyzed which interaction effects are of significant influence on the mode-choice attribute utilities. Here, the same sub-groups as for the route-choice experiment were used for this experiment. The NLogit output of the interaction effects MNL model is added to Appendix P. The utilities of significant effects are displayed as graphs in Appendix Q. Figure 14 shows the impact of the mode-choice attributes including the significant interaction effects. Most interaction effects turned out to be significant on the alternative specific constants. The interactions on public transport are not observed and are hence set to zero effect.

Figure 14 shows the interaction effects on the ASC's for each mode separately and the mode-choice attributes. What can be seen is that the class of people with an age of 36 years and older add much more value to the bicycle than people of an age younger than 36 years. For the car, the opposite is found. Dill and Gliebe (2008) found that in the U.S., females cycle significantly fewer miles than men. Figure 14 does also suggest that males add more value to the bicycle than females. An interesting, though at first unexpected outcome is that the bicycle seems preferred for commuting purposes over recreational purposes and for longer distances rather than short distances as figure 14 shows higher values for each of these sub-classes. This could be explained by the fact that the respondents who were selected for these sub-classes are using the bicycle for commuting purposes and longer distances and could thus be considered as utility cyclists. Once considering this group as utility cyclists, it is conceivable that a higher utility is found for the bicycle.

A proper bicycle parking facility does also have more impact on long distance and commuting cyclists. Besides that, the car travel time is also more important for commuting purposes. On short distances, the presence of a car parking facility does influence the decision to travel with the car more than on long distances. Here, it is also imaginable that on shorter distances, people are more willing to cycle when there is no parking space available for their car.

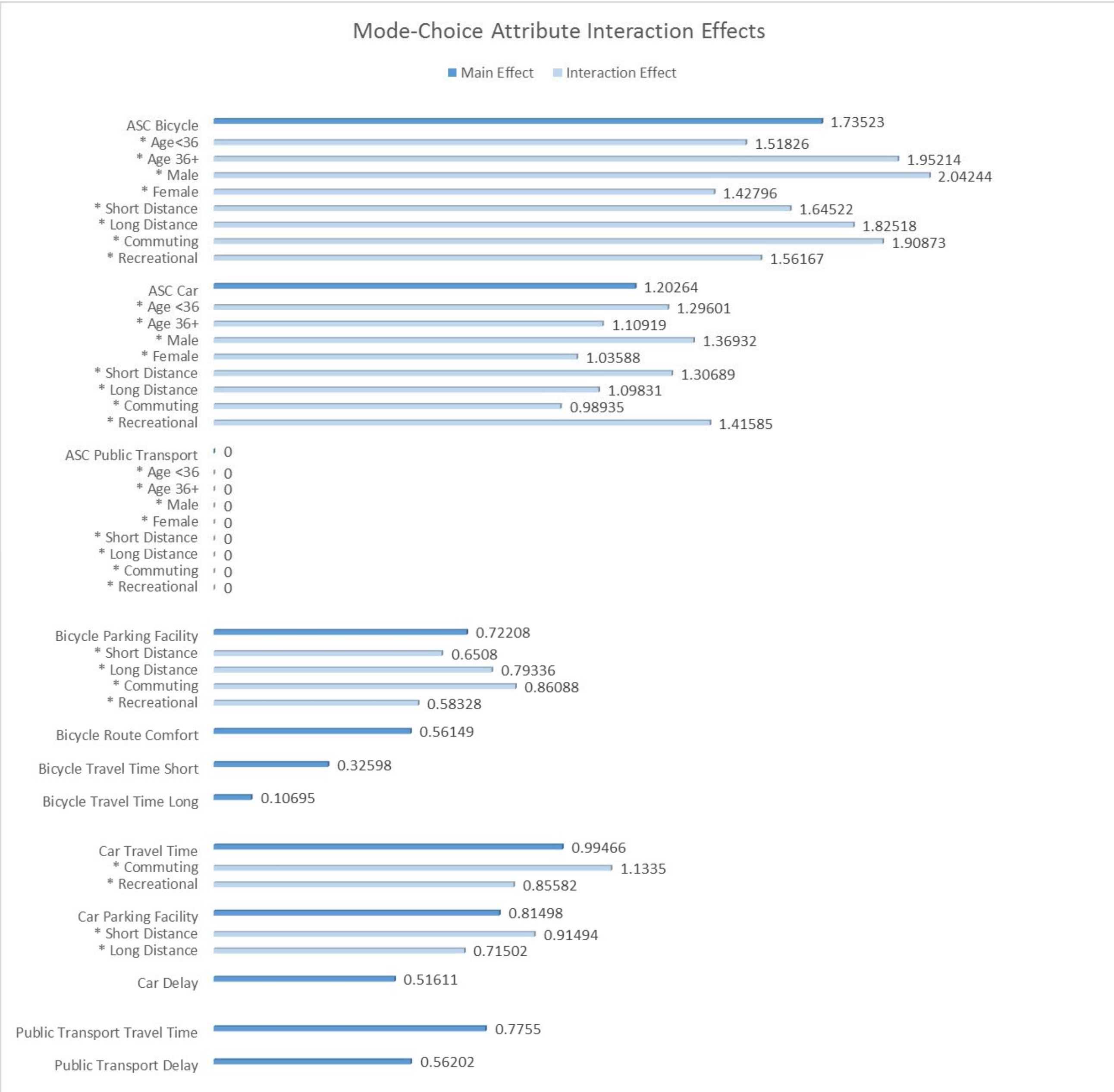


Figure 14: Mode-choice attributes with interaction effects

Regarding the mode-choice model's performance, a rho-squared value of 0.2390 and an adjusted rho-squared value of 0.2368 are found comparing the null model to the optimal model. The main effects only model had a rho-squared value of 0.2118, hence the addition of interaction effects to the model did significantly improve the model fit. Once again, a likelihood ratio test can be performed to check whether the optimal model is a significant improvement to the null model. The null model has a log likelihood of -7198.1077, which is the same as the main effects only model. The optimal model with interaction effects has a log likelihood of -5477.5914, hence the LRS value amounts 3441.0326. Since there are 38 degrees of freedom in the model, a chi-squared value of 70.703 is found for the 99.9% confidence interval. The value of the chi-squared table is again exceeded by the value of the LRS, ergo the optimal model including interaction effects is a significant improvement to the null model.

4.4. Discussion

The goal of this chapter was to find the actual valuation of certain route- and mode-choice aspects. Based on the literature review in chapter 2, a selection of aspects was made to be part of the choice experiment. Regarding the effectiveness of new cycling routes, more insight is wanted in which (comfort) aspects influence bicyclists' route-choice decisions besides the travel time aspect and to what extent this new cycling route contributes to the modal shift from car to bike use. Since investigating a route- and mode-choice task in one experiment would become too complex, the research was divided in three parts.

The first part of the choice experiment investigated the route-choice behavior of cyclists. Where in many literature articles the emphasis on travel time as the most important route-choice aspect exists, in this research several comfort aspects were found more important. For instance, the presence of a cycling facility was most important, followed by a smooth pavement and avoiding hills and slopes on the route. The importance of travel time was investigated as a 2 minute increase or decrease of the middle travel time attribute level. This 2 minute difference on the trip travel time was investigated on long and short distance trips. As expected, the 2 minute reduction of travel time was much less of influence on longer distances, hence the comfort attributes become more important on longer distances. The presence of priority intersections did neither negatively nor positively influence the route-preference of cyclists.

The literature review in chapter 2 showed that many route-specific aspects are also influential on the decision to cycle. It would be interesting to investigate the effect of each route-choice attribute on the mode-choice decisions as well, though since there are more alternative specific attributes which also had to be taken into account, the experiment would become too complex. Hence, during the first experiment, i.e. the route-choice experiment the respondents were asked to select a comfort-rating on a five-star scale to each route alternative. This comfort valuation could be used in the mode-choice experiment, thus by this second route-comfort model the connection is made between the route- and mode-choice experiments. Ordinal regression did not result in a satisfying model performance. Multinomial logistic regression was used to provide more accuracy. A high quality pavement quality was valued as the most important comfort attribute, followed by a separate cycling facility and avoiding slopes.

The separate route-choice aspects could now be merged into one route-comfort attribute which is used for the mode-choice experiment. During the mode-choice experiment, the respondent had to make a decision between the bicycle, car or public transport. Overall, for this research the bicycle had the highest preference to the respondent and therefore had the highest alternative specific constant. Taking parking facilities into account, proved its importance. For the bicycle, the availability of a free and secured parking facility had high influence on the decision to cycle. Next, the hypothesis that route-comfort attributes are of influence on the mode-choice was also confirmed by this experiment. Route-comfort turned out to be more important than travel time reduction of the cycling route by 4 minutes. For the car as a mode, travel time was most important, though the availability of a parking facility also turned out to be significant. Public transport was not seen as a very competitive mode in the experiment, which is conceivable given the rather short trip distances.

5. Application

5.1. Introduction

Besides the purpose of finding values for comfort and travel time aspects in cyclists' route- and mode-choice decisions, the focus of this research was also on the improvement of current traffic models. As described during the literature review in section 2.4.4., the position of the bicycle in traffic models is still marginal. Explanatory variables are missing in the modelling process and in many cases these missing variables are replaced with assumptions based on GPS data or practical knowledge. Since more municipalities are focusing on their cycling policies as part of a sustainable mobility vision, more demand has arisen for proper substantiation of bicycle traffic models. Chapter 4 showed the results of the model analyses and provided some answers to the 'knowledge gap' regarding route- and mode-choice decisions. In this chapter the application of these results is presented. First, several aspects will be compared to the importance of travel time. Since the current traffic models' main focus is on calculating the shortest path by means of distance and travel speed, it is of interest to investigate the other attributes' importance in relation to trip travel times. Second, an example scenario is elaborated to show how the results could be interpreted to calculate trip assignments with the equation as defined in section 3.2.2.. Then finally, a comparison is made between the calculated assignment and a calculation based on the traffic modelling tools for the same scenario. Recommendations will be given for implementation of the results in the traffic model software.

5.2. Elasticities and Choice Probabilities

Chapter 4 already showed the separate attribute's importance, though before continuing with the application of the results, the sensitivity of the respondents' choices regarding marginal changes in the characteristics of alternatives is investigated. This sensitivity is often referred to as the elasticity of the attributes. Ortúzar and Willumsen (2011) describe the elasticity of a dependent variable, which in this case is the choice for a route or mode alternative, as the percentage change of this dependent variable with respect to a given percentage change in the relevant independent variable, which is in this case the route or mode-choice attribute. Normally the elasticity is determined for continuous variables, e.g. time or money where the elasticity is the percentage change in the choice probability for a one percent change in the continuous attribute variable. Since for this research many categorical variables are applicable, a one percent increase does not have any value. A one percent change in bicycle facility type would not be conceivable for instance. Hence here, the change in the choice probability for a certain route or mode alternative is calculated with respect to a categorical change of a specific attribute.

Table 18 shows the choice probability changes of an increase or decrease of an attribute level. The base scenario consists of two route alternatives described by the middle attribute levels. Then, the choice probability for both routes is 50%. Table 18 for instance, shows that when all other attribute levels are hold constant at the middle attribute level, an increase of travel time by two minutes decreases the choice probability of that route alternative by 10.8% relative to the former 50% and a decrease of travel time by 2 minutes increases the choice probability with 10.3% relative to the former 50%. It is necessary to note that these percentage increases do only count for this scenario of two route alternatives described by the middle attribute levels.

Table 18: Route-choice probabilities

Attribute Level Change	*Middle → Worst*	*Middle → Best*	*Range*
Travel Time Short	-10.8%	10.3%	21.1%
Travel Time Long	-4.5%	5.1%	9.6%
Bicycle Facility Type	-23.7%	14.5%	38.2%
Traffic Speed	-2.7%	9.5%	12.3%
Non Priority Intersections	-5.0%	10.5%	15.5%
Priority Intersections	-0.5%	1.2%	1.6%
Traffic Lights	-7.2%	2.1%	9.3%
Slope	-12.9%	10.9%	23.9%
Pavement Quality	-19.6%	13.0%	32.6%

The range in table 18 is a measure of the sensitivity. The higher the range, the more sensitive the choice probability is for a change in the attribute level. Since most traffic models base the route-choices on shortest paths or shortest trip travel times, it is of interest to compare the route-choice probability changes of route-choice attribute changes to changes in travel time. Figure 15 shows the probability changes of attribute changes of slopes, pavement quality, bicycle facility and traffic speed with respect to travel time changes on short distance trips. Note that all other attribute levels are hold constant on the middle level. The larger the vertical gap between the lines in the graphs, the larger the effects.

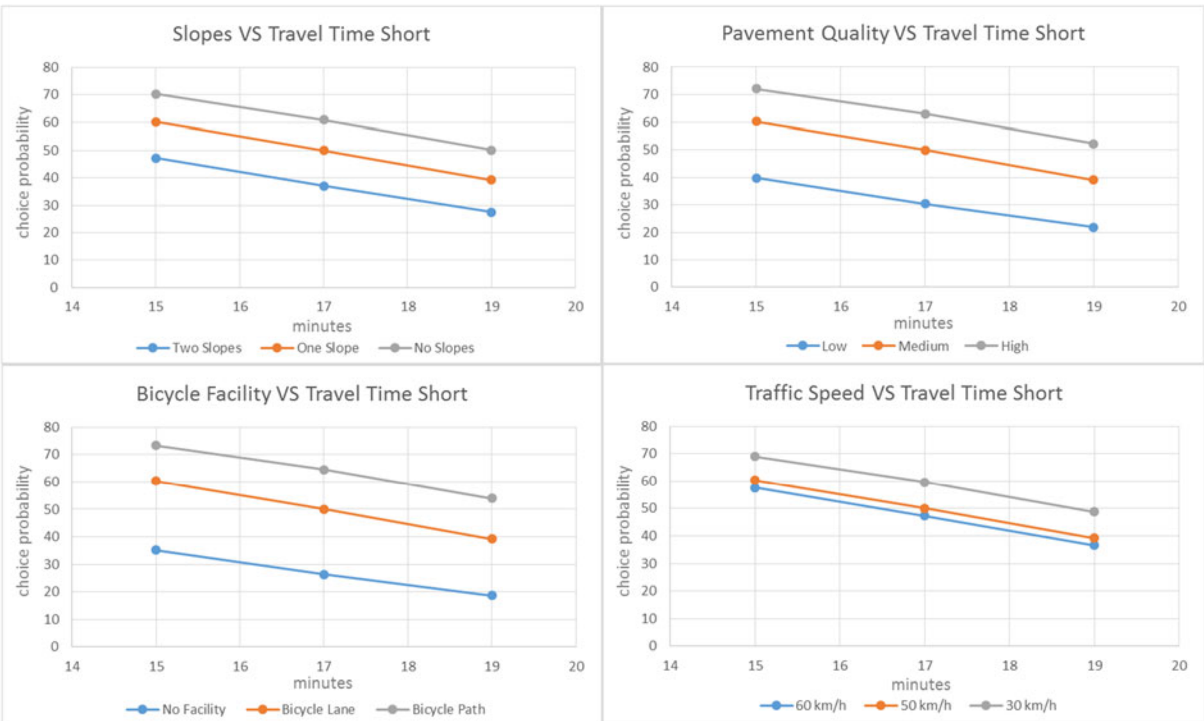


Figure 15: Route-choice probability changes by attribute changes with respect to travel time changes

It can be seen that a route of 15 minutes with low pavement quality can exactly be compensated by a route of 19 minutes travel time with medium quality. Regarding slopes can be seen that the respondents are willing to cycle more than 2 minutes longer to avoid one slope on their route, since a 15 minute route with one slope has the same probability as a 17 minute route with no slopes. These insights are very valuable for transportation planners who are considering different route alternatives.

The same approach as for the route-choice attributes can be used to determine the sensitivity of the mode-choice probability. Table 19 shows the sensitivity of the mode-choice probability of choosing for the bicycle. Since bicycle travel time savings on the longer distances turned out to be insignificant on the mode-choice, table 19 is only based on the effects of short distance travel times. For this example the base scenario is taken where all modes are described by the middle attribute levels and their ASC values. Since this is a labeled scenario, the mode alternatives do not have the same probability of being chosen in the base. Using the ASC values while holding all other attributes constant on the middle level gives a choice probability for choosing the bicycle, car and public transport of respectively 57.3%, 32.8% and 9.9%. Thus, table 19 shows the increases of the choice probability for the bicycle regarding this latter base scenario.

Table 19: Mode-choice probabilities for the bicycle

Attribute Level Change	*Middle → Worst*	*Middle → Best*	*Range*
Bicycle Travel Time Short	-2.8%	4.1%	6.9%
Bicycle Parking Facility	-3.5%	12.6%	16.1%
Bicycle Route-Comfort	-8.7%	4.7%	13.4%
Car Travel Time	6.9%	-10.8%	17.7%
Car Delay	3.1%	-6.2%	9.3%
Car Parking Facility	7.9%	-6.6%	14.4%
Public Transport Travel Time	2.0%	-2.2%	4.2%
Public Transport Delay	0.7%	-2.8%	3.5%

What can be seen from table 19 is that changing a free non-secured parking facility to a free secured parking facility leads to a large increase in the choice for the bicycle as a mode of transport in this situation. The attribute levels of the car do also seem to have significant influence on the mode-choice. As can be seen, public transport does not influence the mode-choice decision that much. Figure 16 again, shows the effect on the choice probability for the bicycle with respect to travel time changes. The route-comfort comparison shows that when a route has 15 minutes travel time and a one-star comfort, the probability to choose for the bicycle is approximately the same as for a route which is 4 minutes longer, thus 19 minutes when this route has a three-star comfort rating. The bicycle parking facility comparison shows that providing free secured parking facilities increases the travel time allowance a lot. Hence, the distance radius in which people are considering to take the bicycle as a mode is increased quite a lot. This information is very useful for companies who want to attract more commuting cyclists for instance.

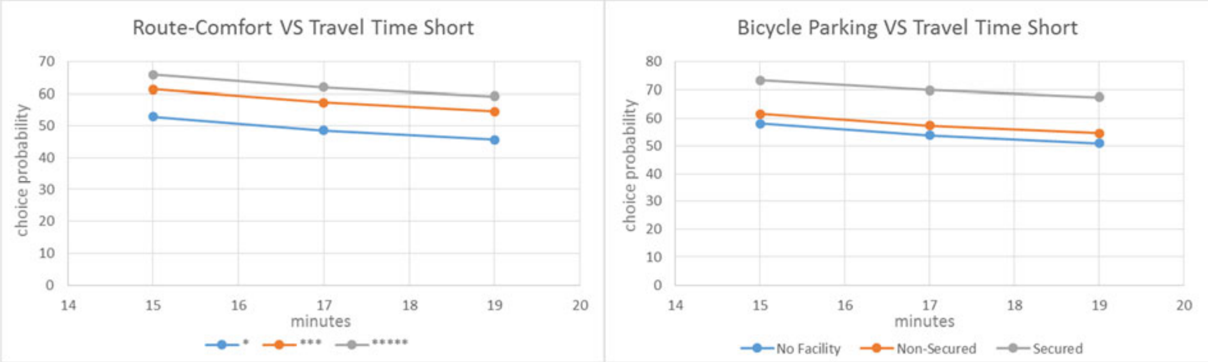


Figure 16: Mode-choice probability changes for the bicycle by attribute changes with respect to travel time changes

5.3. Scenario Analysis

For this section the existing case of a fast cycle route between the municipality of Valkenswaard and Eindhoven is taken as an example to demonstrate how the results could be applied to a real-life situation. The fast cycle route is located on a former railroad track and is therefore a direct connection between the municipalities and consists of a comfortable high quality pavement. This new bicycle path does also connect the smaller municipalities of Waalre and Aalst, which are located between Valkenswaard and Eindhoven. Hence it is not only of interest to investigate the use of this fast cycle route by cyclists from Valkenswaard to Eindhoven, though also from Valkenswaard to Waalre for instance. The latter case is used for the scenario in this section.

Figure 17 on the next page shows the situation with the area of Valkenswaard and Waalre. Cyclists who are travelling from the 'Geenhovensedreef' in Valkenswaard (Green mark) to Waalre 'Markt' (Red mark) can choose for the shortest path (about 4,5 km distance) on the 'Heikantstraat', which is the blue-colored Route A in figure 17 or they can cycle on the 'Oude Spoorbaan' which is the yellow-colored fast cycle route B on the right in figure 17 (with a distance of around 5.2 km). Route A is a separate bicycle path with medium quality pavement located next to a road with a speed limit of 60 km/h. Route B is the high quality fast cycle route located in a quiet environment though requires the cyclist to cycle a longer distance to their destination.

Figure 18 gives an impression of the two routes with the bicycle facility next to the Heikantstraat on Route A on the left and the fast cycle Route B on the right. Note that the bicycle path on Route A is considered as a medium quality pavement and Route B as a high quality pavement. As can be seen in figure 17, there are different car speeds on the routes, these are taken into account. Furthermore, Route A crosses a roundabout where the bicyclist has priority and has one non-priority intersection on the route. The whole route consists of a separate bicycle path till this non-priority intersection. After this intersection there is no cycling facility available. Route B requires the cyclist to pass a traffic light before reaching the high quality route. Although the fast cycle route is not located next to a road, a traffic speed of 30 km/h is considered for the route since this was the 'best' case in the experiment. Once in Waalre, the cyclist has to cross the road on a non-priority intersection and continues its route on a bicycle lane with one more traffic light on the route.

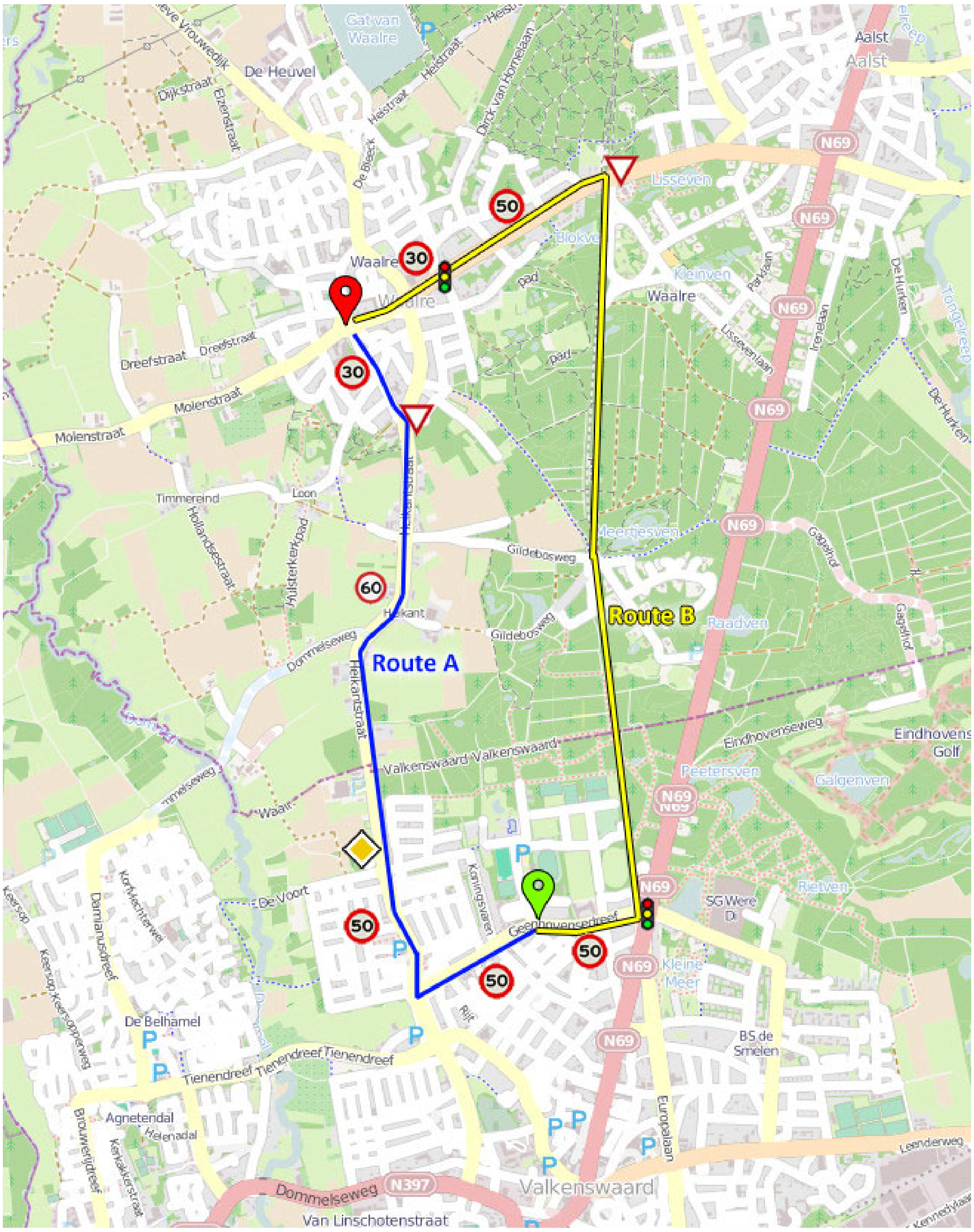


Figure 17: Example route alternatives from Valkenswaard to Waalre

Figure 18: Pavement quality of the route alternative A (left) and alternative B (right)

Table 20 shows both route alternatives' properties based on the characteristics which are investigated in chapter 4. The travel time is based on a cycle speed of 18 km/h as suggested by the Dutch Cyclists Union. Table 20 shows that although Route B has a longer distance than Route A, it is still preferred over Route A due to the higher utility.

Table 20: Route alternative utilities

Attribute Level Change	*Route A*		*Route B*	
Travel Time	*15 minutes*	0.424	*17 minutes*	0.007
Bicycle Facility Type	*Bicycle Path*	0.742 * 87.5%	*Bicycle Path*	0.742 * 90.4%
	Bicycle Lane	0.144 * 0%	*Bicycle Lane*	0.144 * 9.6%
	No Facility	-0.886 * 12.5%	*No Facility*	-0.886 * 0%
Traffic Speed	*30 km/h*	0.294 * 12.5%	*30 km/h*	0.294 * 84.6%
	50 km/h	-0.092 * 47.5%	*50 km/h*	-0.092 * 15.4%
	60 km/h	-0.201 * 40.0%	*60 km/h*	-0.201 * 0%
Non Priority Intersections	*1*	-0.074	*1*	-0.074
Priority Intersections	*1*	-0.009	*n.a.*	0.037
Traffic Lights	*n.a.*	0.152	*2*	-0.076
Slope	*n.a.*	0.473	*n.a.*	0.473
Pavement Quality	*High*	0.630 * 0%	*High*	0.630 * 71.2%
	Medium	0.098 * 100%	*Medium*	0.098 * 28.8%
Total Route Utility		***1.515***		***1.763***

Applying equation (5) from section 3.2.2. gives the following probability that Route B is chosen by an individual when Route A and Route B are the alternatives to choose from:

$$P_{Route\ B} = \frac{e^{1.763}}{e^{1.515} + e^{1.763}} = 0.562$$

Thus, from the above filled in equation follows that 56.2% of the cyclists will choose to cycle on Route B and hence 43.8% of the cyclists decides to cycle on the shortest route in this scenario. In the next section, these results are compared to the calculated assignment according to conventional traffic models.

5.4. Traffic Model Comparison

The literature review in Chapter 2 already provided an explanation of the available traffic models and how these are applied to predict travel behavior as a result of taken measures or newly created routes. As mentioned, the four-step model is still the most applied model form for traffic demand modelling. For bicycle traffic modelling, often the so-called 'all-or-nothing' assignment method is used. Here, it is assumed that no capacity restrictions are applicable, hence no congestion may occur and that the road users always choose the shortest path. As also stated in chapter 4, it is not realistic to assume that all cyclists will choose the shortest path and act in such rational way that they always know which path is the best to choose. Hence, the stochastic assignment method is more successful for bicycle traffic modelling (Immers & Stada, 2011). This method is used to calculate the probability that one chooses a certain route alternative given different route aspects. In this section the results of section 5.3 are compared to a calculation of the same scenario using the assumptions which are applied in current traffic models.

In the classic four-step traffic models, origin and destination matrices are used to determine the traffic flows on the existing infrastructural network. For the example case as described in section 5.3, there is only one point of origin and one point of destination used. The number of cyclists is based on travel data and actual counting of cyclists. When entering the example scenario in current traffic modelling tools of Royal HaskoningDHV with a stochastic assignment method, a much different assignment is found. This is probably due to the assumption in the tool that road quality does not outweigh the shortest path preference to such an extent as the found results in this research do. According to the used tool of Royal HaskoningDHV, without calibration to actual counting data, only 32.5% will consider cycling on Route B and 67.5% will cycle on the shortest path, Route A. Hence, in contrary to the found assignment in section 5.3, the high quality fast cycle route is not preferred over the shortest route for most of the cyclists. Implementing the route-choice aspects as investigated in this research in combination with a stochastic assignment method using the logit function as above, can contribute to better and more accurate route-choice models.

5.5. Conclusion

This chapter provided an example of how the results of chapter 4 regarding route-choice behavior can be interpreted and used in a real-life situation. With the available results, a grounded utility value can be calculated for each route alternative. The comparison to a traffic modelling tool showed that there is still an underestimation of the effect of route-comfort aspects on route-choice decisions. Although the used tool of Royal HaskoningDHV did allow considering route quality as a factor of route-choice by assigning different cycling speeds to bicycle paths, still a large difference was found in the comparison.

Current models consist of the assumption that only the travel time of a route is important and only the waiting time at an intersection is of influence. Chapter 4 already showed that there exists a difference in the utility values of different intersection types. A traffic light with an average waiting time of 30 seconds for instance is according to current traffic models valued the same as a non-priority intersection with an average waiting time of 30 seconds, while in chapter 4 was found that a traffic light will be preferred over the non-priority intersection probably due to the perceived safety with this intersection type. This is also applicable to the travel time on network links or paths, since the conventional modelling tools do not take into account different perceptions of cycling for 15 minutes on a low quality path or cycling for 15 minutes on a high quality path (assuming the same cycling speed on each path in the model). Section 5.3 showed that taking into consideration other properties of the bicycle paths may considerably affect the utilities of the alternative routes compared to only considering the travel times of the route alternatives.

In order to further implement the results and improve the predictive power of current traffic models, a more accurate network layer for bicycle infrastructure should be created. Each road type has to be defined by the investigated aspects. Discrete choice modelling has already proved its success in transportation research, but proves to be even more useful when more aspects are of influence than only travel time reduction. Hence, for the bicycle the gravity models should be replaced by discrete choice models for more accurate traffic assignment.

6. CONCLUSIONS

6.1. General Conclusion

The objective of this research as stated earlier in chapter 1 was to get more insight in the effectiveness of new or improved bicycle infrastructure and facilities on the route-choice decisions and the propensity to cycle of the respondents. Besides the high demand for this insight in influential aspects, an approach to implement the results in traffic models as an improvement was sought-after. Therefore the main research question was as follows:

"What is the influence of comfort aspects in comparison to travel time savings on route- and mode-choice decisions of cyclists, and how can these insights improve current traffic modelling tools?"

In order to be able to answer this question, several sub-questions have to be answered:

- *"What are the comfort aspects in bicycle infrastructure according to current literature?"*

In order to provide an answer to this question, the results of a very extensive literature review have been presented in chapter 2. Many articles were analyzed to find the influential attributes on route –and mode-choice decisions. Remarkable is that most of the researches did not consist of a clear definition of comfort. The value of such results decreases instantly by the fact that policy makers do not know in which specific measures to invest in order to increase the perceived comfort by cyclists. A summarizing table in Appendix A shows a very comprehensive list of attributes, with an elaboration on comfort specific aspects, which are influential on route –and mode choice decision making. This list shows that many attributes influence both route- as well as mode-choice decisions. Besides that, not all attributes can be influenced by policy makers for instance. Briefly, Appendix A provides the answer to the sub-question according to existing literature. Based on this literature a selection of attributes was made for the actual choice experiment, since the list is too comprehensive to take all aspects into account.

In this research, the model analyses turned out that there exists some variation in the valuation of comfort, though from most to least important the following attributes were considered influential on the perception of comfort: *'Pavement Quality'; 'Bicycle facility type'; 'Slope'; 'Traffic speed'; 'Non-priority intersections';* and *'Traffic light intersections'*. The presence of *'Priority intersections'* did not significantly influence the perception of comfort.

- *"Which (other) factors influence the route-choice behavior of cyclists?"*

The most common used attribute in existing literature concerning route- and mode-choice decisions is *'Travel time'*. Several other attributes are of influence on decision making. A large diversity of categories of attributes exists in the literature, though overall these are covered by the following factors: *'Trip purpose'*; *'Demographic factors'*; *'Social cultural factors'*; *'Spatial economic factors'*; *'Physical factors'*; and *'Traffic and transportation factors'.*

The pilot questionnaire for this research emphasized the importance of defining the right decision context to the respondent. For the conducted experiments, the trip purpose was one of those important decision context attributes. The model analyses also turned out that for the demographic aspects *'Gender'* and *'Age'* significantly different behavior was found.

- *"Which (other) factors influence the transportation mode-choice?"*

For the mode-choice experiment, the decisions to choose for a specific mode were mainly based on the respondents' perceptions towards the mode alternatives (ASC). Besides these attitudes, the model results also showed that the mode-choice decisions are also based on the *'Travel time'* and *'Travel time delay*'. Regarding the propensity to cycle, the availability of a secured *'Bicycle parking facility'* and a decent *'Route-comfort'* were found more important than the travel time of the route. Hence, providing proper bicycle facilities certainly has impact on the decision to cycle. Appendix A also shows other attributes which may contribute to the mode-choice decisions as defined in existing literature.

- *"What is the actual valuation of comfort aspects in bicycle infrastructure in comparison to travel times, regarding route-and mode-choice decisions?"*

Although many researchers have stated that travel time reduction is the most important route-choice attribute, the results in this research proved that the decisions are more influenced by a proper *'Bicycle facility'*, with a smooth *'Pavement quality'* and avoiding *'Slopes'* on the route than reducing *'Travel time'* by 4 minutes. It was assumed that travel time reductions of 2 minutes have more impact on short distance routes than long distance routes. Hence, a distinction was made in two distance classes. The results confirmed that the valuation of travel time reduction on longer and shorter distances differ. Thus, comfort aspects have much higher value (utility) relative to travel time reduction on longer distances than on shorter distances. Chapter 5 showed the comparison of the travel time attribute to comfort aspects. The figures showed that an increase in travel time of 4 minutes will be compensated by an improvement of the pavement quality from a low quality level to a medium quality level.

As mentioned in the answer on previous question considering mode-choice, bicycle facilities were also found more important than travel time regarding mode-choice decisions. A secured bicycle parking facility or a high route-comfort were valued much more than a shorter route regarding the propensity to cycle. Chapter 5 showed that an upgrade from a non-secured free-of-charge bicycle parking facility to a secured free-of-charge parking facility allows a much higher travel time for the same mode-choice probability. Hence, providing secured bicycle parking facilities will probably attract more cyclists from larger distances of the destination.

- *"What is the current practice of transport modelling?"*

The literature review on transport modelling presented the classic four-step model and further elaborated on the applications of the activity-based model types. The activity-based traffic models have much potential for future transportation planning, since its focus is on individual movements and schedules. More personal data will be available in the future, resulting in easier implementation of these models. Currently, the four-step model still dominates the practice of transportation planning, which has its downsides. Although recent developments show improvements of these classic model implementations, the position of bicyclists in traffic models is still marginal, since bicycle traffic is simulated with assumptions of car traffic flows.

- *"How can the results be implemented in current traffic models and be useful for transport planning in practice?"*

The utilities of all route-choice attributes can be used to simulate scenarios. Current bicycle infrastructure planning is based on assumptions of route-choice behavior and mainly focuses on maximizing route directness. With the results of the multinomial logit models, a more accurate distribution of cyclists on the network can be calculated. Implementing these results in traffic simulation software has therefore high potential. Chapter 5 showed that the application of the results and the comparison to a simulation with a conventional traffic modelling tool resulted in large differences of traffic assignment to the route alternatives. The added value of comfort aspects on route-choice is now more insightful and provides the ability to make a grounded statement about the effectiveness of new planned routes. The mode-choice experiment did also take into account a comfort-aspect which could be implemented in the modal split calculations in the conventional traffic modelling tools. Then, the effectiveness regarding route-choice is not only known, though also the effectiveness of an infrastructure improvement on the propensity to cycle can be predicted.

By having provided an answer on all sub-questions, an answer is given to the main question of this research.

6.2. General Discussion & Recommendations

Research concerning bicyclists behavior has gained increased attention recently, though a fundamental theoretical substantiation of aspects which influence route- and mode-choice behavior is still not available. The purpose of this research was to contribute to the development of such a theoretical substantiation, by providing more insight in specific comfort attributes besides travel time. Where many researchers have concluded that a more comfortable route is preferred over a shorter route, an elaborated definition of comfort is often missing. In this report, a comprehensive overview is given of existing literature in the field of bicycle transportation research. A selection of these attributes is selected to continue the research with, hence it is also recommended for further research to take other attributes into account which, for this research were left out. This section will provide recommendations for future research regarding cyclists' behavior as well as recommendations for better bicycle traffic modelling.

For this research an online panel was used to recruit the respondents for the experiments. The sample population was recruited based on the distribution of demographic aspects of the population of the Netherlands. Besides that, the respondents were selected on bicycle usage and were screened out of the research when they never make use of the bicycle as a transport mode. To make a statement about the fit of the dataset for the average Dutch cyclist, a comparison should be made to actual travel data, hence the data should not be applied to the general population though is applicable to cyclists.

The revealed preference part in the questionnaire showed that a major part of the respondents agreed on changing their route for a better scenery. More research could be conducted to find a proper valuation of environmental quality and its effect on route- and mode-choice decisions.

Although in this research a distinction was made between two distance classes for bicycle routes, only utility values for 15 to 19 minute and 25 to 29 minute routes were investigated. Travel times outside these ranges should be treated with caution. Future research should consider the effect of travel time for other ranges of travel time.

Earlier research already proved the applicability of discrete choice models for transportation research. For the scope of this research and the ease of interpretation, only the multinomial logit model has been applied. Further research could be done using the mixed logit approach, taking into account the individual's taste variations. During the route-choice experiment, some significant interaction effects were found between several subgroups based on revealed preference and demographic data. For the chosen orthogonal design, interaction effects among the attributes themselves could not be investigated. Further research might consider interaction effects between for instance, the traffic speed of car traffic and the valuation of a bicycle facility since it is assumed that these values are interrelated.

Regarding the route-comfort valuation, the ordinal regression did not have an acceptable model fit. For this variable, a five-star comfort-rating was chosen since it was assumed that this would lead to more accuracy in predicting the level of comfort. The analysis did however turn out that the extreme comfort-ratings of one-star and five-star levels were hardly chosen, which resulted in the lower predictive power of the model. The application of multinomial logistic regression had a better model fit, but was harder to interpret. An advise for future research would be to take three-star comfort level valuations.

Finally, the mode-choice experiment analysis showed that almost 30% of the respondents chose nine times for the bicycle during all nine choice tasks and 10% chose always for the car. This resulted into high values for the ASC's. Although in reality there are also stubborn car drivers and utility cyclists, it seems probable that the cyclist is overly represented in this research. Hence, the results of the mode-experiment should not be treated as applicable to the general population of the Netherlands.

This research presented a comparison of the results' application to a simulation of conventional traffic modelling tools. Implementation of these parameters in these conventional models is the next step in the improvement process. More precision is required for developing the bicycle infrastructure network in traffic models and other assignment methods than the 'all-or-nothing' assignment method should be considered.

References

Abdel-Aty, M. A., Kitamura, R., & Jovanis, P. P. (1997). Using stated preference data for studying the effect of advanced traffic information on drivers' route choice. *Transportation Research Part C: Emerging Technologies*, *5*(1), 39–50. http://doi.org/10.1016/S0968-090X(96)00023-X

Accenture. (2014). Low-Carbon Mobility Report. Retrieved from http://urbantransform.eu/wp-content/uploads/sites/2/2013/02/20141002-low-carbon-mobility-low-res.pdf

Akar, G., & Clifton, K. J. (2010). Influence of Individual Perceptions and Bicycle Infrastructure on Decision to Bike. *Transportation Research Record: Journal of the Transportation Research Board*, *2140*, 165–172. http://doi.org/10.3141/2140-18

Algers, S., Eliasson, J., & Mattsson, L. G. (2005). Is it time to use activity-based urban transport models? A discussion of planning needs and modelling possibilities. *Annals of Regional Science*, *39*(4), 767–789. http://doi.org/10.1007/s00168-005-0016-8

Arentze, T., & Timmermans, H. (2008). ALBATROSS: overview of the model, application and experiences. Innovation in Travel Modeling 2008 Conference, Portland, June 2008, 1–11.

Axhausen, K. W., & Gärling, T. (1992). Activity-based approaches to travel analysis: conceptual frameworks, models, and research problems. *Transport Reviews*. http://doi.org/10.1080/01441649208716826

Bates, J. (2008). History of demand modelling. In D. A. Hensher & K. J. Button (Eds.), *Handbook of Transport Modelling* (Second Edi, pp. 11–34). Elsevier Ltd.

Beckx, C., Int Panis, L., Van De Vel, K., Arentze, T., Lefebvre, W., Janssens, D., & Wets, G. (2009). The contribution of activity-based transport models to air quality modelling: A validation of the ALBATROSS-AURORA model chain. *Science of the Total Environment*, *407*(12), 3814–3822. http://doi.org/10.1016/j.scitotenv.2009.03.015

Beecham, R., & Wood, J. (2014). Exploring gendered cycling behaviours within a large-scale behavioural data-set. *Transportation Planning and Technology*, *37*(1), 83–97. http://doi.org/10.1080/03081060.2013.844903

Beheshtitabar, E., Aguilar Ríos, S., König-Hollerwöger, D., Svatý, Z., & Rydergren, C. (2014). Route choice modelling for bicycle trips. *International Journal for Traffic and Transport Eingineering*, *4*(2), 194–209.

Ben-Akiva, M. E., & Bowman, J. L. (1998). Activity Based Travel Demand Model Systems. In P. Marcotte & S. Nguyen (Eds.), *Equilibrium and Advanced Transportation Modelling* (pp. 27–46). Springer US. http://doi.org/10.1007/978-1-4615-5757-9_2

Ben-Akiva, M., & Lerman, S. R. (1985). *Discrete Choice Analysis: Theory and Application to Travel Demand*. MIT Press.

Bernhoft, I. M., & Carstensen, G. (2008). Preferences and behaviour of pedestrians and cyclists by age and gender. *Transportation Research Part F: Traffic Psychology and Behaviour*, *11*(2), 83–95. http://doi.org/10.1016/j.trf.2007.08.004

Bifulco, G. N., Cartenì, A., & Papola, A. (2010). An activity-based approach for complex travel behaviour modelling. *European Transport Research Review*, *2*(4), 209–221. http://doi.org/10.1007/s12544-010-0040-3

Björklund, G., & Mortazavi, R. (2013). Influences of infrastructure and attitudes to health on value of travel time savings in bicycle journeys. *Centre for Transport Studies Stockholm*, 1–36. Retrieved from http://swopec.hhs.se/ctswps/abs/ctswps2013_035.htm

Bonsall, P. W. (1997). Principles of transport analysis and forecasting. In C. A. O'Flaherty (Ed.), *Transport Planning and Traffic Engineering* (pp. 103–131). London: ARNOLD.

Börjesson, M., & Eliasson, J. (2012). The value of time and external benefits in bicycle appraisal. *Transportation Research Part A: Policy and Practice*, *46*(4), 673–683. http://doi.org/10.1016/j.tra.2012.01.006

Bovy, P. H. L., & Stern, E. (1990). *Route Choice: Wayfinding in Transport Networks*. Kluwer Academic Publishers.

Bowman, J. L., & Ben-Akiva, M. E. (2000). Activity-based disaggregate travel demand model system with activity schedules. *Transportation Research Part A: Policy and Practice*, *35*(1), 1–28. http://doi.org/10.1016/S0965-8564(99)00043-9

Boyce, D. E., Zhang, Y.-F., & Lupa, M. R. (1994). Introducing " Feedback " into Four-Step Travel Forecasting Procedure Versus Equilibrium Solution of Combined Model. *Transportation Research Record*, *10*, 123–142.

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. http://doi.org/10.1016/j.tra.2012.07.005

Button, K. (2014). Travel Behavior and Travel Demand. In M. M. Fischer & P. Nijkamp (Eds.), *Handbook of Regional Science* (pp. 685–703). Springer-Verlag Berlin Heidelberg. http://doi.org/10.1007/978-3-642-23430-9

Carse, A., Goodman, A., Mackett, R. L., Panter, J., & Ogilvie, D. (2013). The factors influencing car use in a cycle-friendly city: The case of Cambridge. *Journal of Transport Geography*, *28*, 67–74. http://doi.org/10.1016/j.jtrangeo.2012.10.013

Carson, R. T., Louviere, J. J., Anderson, D. a., Arabie, P., Bunch, D. S., Hensher, D. a., … Wiley, J. B. (1994). Experimental analysis of choice. *Marketing Letters*, *5*(4), 351–367. http://doi.org/10.1007/BF00999210

Caulfield, B., Brick, E., & McCarthy, O. T. (2012). Determining bicycle infrastructure preferences - A case study of Dublin. *Transportation Research Part D: Transport and Environment*, *17*(5), 413–417. http://doi.org/10.1016/j.trd.2012.04.001

CBS. (2015). Bevolking Kerncijfers. Retrieved December 1, 2015, from http://statline.cbs.nl/Statweb/selection/?DM=SLNL&PA=37296NED&VW=T

Cervero, R., & Duncan, M. (2003). Walking, Bicycling, and Urban Landscapes: Evidence from the San Francisco Bay Area. *American Journal of Public Health*, *93*(9), 1478–1483. http://doi.org/10.2105/AJPH.93.9.1478

Chataway, E. S., Kaplan, S., Nielsen, T. A. S., & Prato, C. G. (2014). Safety perceptions and reported behavior related to cycling in mixed traffic: A comparison between Brisbane and Copenhagen. *Transportation Research Part F: Traffic Psychology and Behaviour*, *23*, 32–

43. http://doi.org/10.1016/j.trf.2013.12.021

ClimateNewsNetwork. (2014). Clean urban transport can drive emissions cuts, (24 september). Retrieved from http://www.climatenewsnetwork.net/clean-urban-transport-can-drive-emissions-cuts/

CROW fietsberaad. (2015). Fiets blinde vlek in verkeersmodellen. Retrieved September 25, 2015, from http://www.fietsberaad.nl/?section=nieuws&mode=newsArticle&newsYear=2015&repository=Fiets+blinde+vlek+in+verkeersmodellen

Cui, Y., Mishra, S., & Welch, T. F. (2014). Land use effects on bicycle ridership: a framework for state planning agencies. *Journal of Transport Geography*, *41*, 220–228. http://doi.org/10.1016/j.jtrangeo.2014.10.004

Dalton, A. M., Jones, A. P., Panter, J., & Ogilvie, D. (2014). Are GIS-modelled routes a useful proxy for the actual routes followed by commuters? *Journal of Transport & Health*, 1–11. http://doi.org/10.1016/j.jth.2014.10.001

Davidson, W., Donnelly, R., Vovsha, P., Freedman, J., Ruegg, S., Hicks, J., … Picado, R. (2007). Synthesis of first practices and operational research approaches in activity-based travel demand modeling. *Transportation Research Part A: Policy and Practice*, *41*(5), 464–488. http://doi.org/10.1016/j.tra.2006.09.003

De Graaf, S., Hoogendoorn, S., & Barmentlo, H. (2015). De opleving van modellering van langzaam verkeer. *NM-Magazine*, *10*(3), 18–19. Retrieved from http://www.nm-magazine.nl/pdf/NM_Magazine_2015-3.pdf

Dill, J., & Gliebe, J. (2008). Understanding and Measuring Bicycling Behavior: A Focus on Travel Time and Route choice. *Final Report OTREC-RR-08-03 Prepared for Oregon Transportation Research and Education Consortium (OTREC)*, (December). Retrieved from http://scholar.google.co.uk/citations?view_op=view_citation&hl=en&user=GNyEzcMAAAAJ&citation_for_view=GNyEzcMAAAAJ:UeHWp8X0CEIC

Dill, J., & Voros, K. (2006). Factors Affecting Bicycling Demand: Initial Survey Findings from the Portland, Oregon, Region. *Submission for Presentation and Publication of the 86th Annual Meeting of the Transportation Research Record*, 9–17. http://doi.org/10.3141/2031-02

Ehrgott, M., Wang, J. Y. T., Raith, A., & Van Houtte, C. (2012). A bi-objective cyclist route choice model. *Transportation Research Part A: Policy and Practice*, *46*(4), 652–663. http://doi.org/10.1016/j.tra.2011.11.015

European Commission. (2010). Europe 2020 targets. Retrieved from http://ec.europa.eu/europe2020/targets/eu-targets/index_en.htm

Gan, H., & Bai, Y. (2013). The effect of travel time variability on route choice decision: a generalized linear mixed model based analysis. *Transportation*, 1–12. http://doi.org/10.1007/s11116-013-9481-6

Gatersleben, B., & Appleton, K. M. (2007). Contemplating cycling to work: Attitudes and perceptions in different stages of change. *Transportation Research Part A: Policy and Practice*, *41*(4), 302–312. http://doi.org/10.1016/j.tra.2006.09.002

Gatersleben, B., & Uzzell, D. (2007). Affective Appraisals of the Daily Commute: Comparing Perceptions of Drivers, Cyclists, Walkers, and Users of Public Transport. *Environment and Behavior*, *39*(3), 416–431. http://doi.org/10.1177/0013916506294032

Gössling, S. (2013). Urban transport transitions: Copenhagen, city of cyclists. *Journal of Transport Geography*, *33*, 196–206. http://doi.org/10.1016/j.jtrangeo.2013.10.013

Haybatollahi, M., Czepkiewicz, M., Laatikainen, T., & Kyttä, M. (2015). Neighbourhood preferences, active travel behaviour, and built environment: An exploratory study. *Transportation Research Part F: Traffic Psychology and Behaviour*, *29*, 57–69. http://doi.org/10.1016/j.trf.2015.01.001

Heinen, E., & Chatterjee, K. (2015). The same mode again? An exploration of mode choice variability in Great Britain using the National Travel Survey. *Transportation Research Part A: Policy and Practice*, *78*, 266–282. http://doi.org/10.1016/j.tra.2015.05.015

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. http://doi.org/10.1016/j.trd.2010.08.010

Heinen, E., van Wee, B., & Maat, K. (2010). Commuting by Bicycle: An Overview of the Literature. *Transport Reviews*, *30*(1), 59–96. http://doi.org/10.1080/01441640903187001

Hensher, D. A., & Button, K. J. (2008). Introduction. In D. A. Hensher & K. J. Button (Eds.), *Handbook of Transport Modelling* (Second Edi, pp. 1–10). Elsevier Ltd.

Hensher, D. A., Rose, J. M., & Greene, W. H. (2005). *Applied Choice Analysis*. Cambridge University Press.

Hensher, D. A., Rose, J. M., & Greene, W. H. (2015). *Applied Choice Analysis* (Second Edi). Cambridge University Press. http://doi.org/10.1017/CBO9780511610356

Hood, J., Sall, E., & Charlton, B. (2011). A GPS-based bicycle route choice model for San Francisco, California. *Transportation Letters: The International Journal of Transportation Research*, *3*(1), 63–75. http://doi.org/10.3328/TL.2011.03.01.63-75

Hoogendoorn, R., & Meurs, H. (2015). Menselijk gedrag in verkeersmodellen. *NM-Magazine*, *10*(3), 16–17. Retrieved from http://www.nm-magazine.nl/pdf/NM_Magazine_2015-3.pdf

Huisman, D. J., & Hengeveld, J. (2014). *Opmaak van een methode voor fietstellingen in de provincie Antwerpen*. Royal HaskoningDHV.

Hunt, J. D., & Abraham, J. E. (2001). Influences on bicycle use. *Transportation*, *34*(4), 453–470. http://doi.org/10.1007/s11116-006-9109-1

Hyodo, T., Suzuki, N., & Takahashi, K. (2000). Modeling of Bicycle Route and Destination Choice Behavior for Bicycle Road Network Plan. *Transportation Research Record*, *1705*, 70–76.

Immers, L. H., & Stada, J. E. (2011). *Verkeersmodellen*. Leuven: Katholieke Universiteit Leuven. Retrieved from https://www.mech.kuleuven.be/cib/verkeer/dwn/cursusteksten-voor-2011/h01i6a-deel1-verkeersmodellen-uitgave2011.pdf

Kitamura, R. (1988). An evaluation of activity-based travel analysis. *Transportation*, *15*, 9–34.

Krizek, K. J., El-Geneidy, A., & Thompson, K. (2007). A detailed analysis of how an urban trail system affects cyclists' travel. *Transportation*, *34*(5), 611–624. http://doi.org/10.1007/s11116-007-9130-z

Krizek, K. J., Handy, S. L., & Forsyth, A. (2009). Explaining changes in walking and bicycling behavior: Challenges for transportation research. *Environment and Planning B: Planning and Design*, *36*(4), 725–740. http://doi.org/10.1068/b34023

Krizek, K. J., Johnson, P. J., & Tilahun, N. (2005). Gender Differences in Bicycling Behavior and Facility Preferences. *Transportation Research Board Conference Proceedings*, (August 2015), 31–40.

Liedtke, G., & Schepperle, H. (2004). Segmentation of the transportation market with regard to activity-based freight transport modelling. *International Journal of Logistics: Research and Applications*, *7*(3), 199–218. http://doi.org/10.1080/13675560412331298464

Liu, H. X., Recker, W., & Chen, A. (2004). Uncovering the contribution of travel time reliability to dynamic route choice using real-time loop data. *Transportation Research Part A: Policy and Practice*, *38*(6), 435–453. http://doi.org/10.1016/j.tra.2004.03.003

Louviere, J. J., Hensher, D. A., & Swait, J. D. (2000). *Stated Choice Methods - Analysis and Applications*. UK: Cambridge University Press.

Majumdar, B. B., & Mitra, S. (2013). Investigating the Relative Influence of Various Factors in Bicycle Mode Choice. *Procedia - Social and Behavioral Sciences*, *104*, 1120–1129. http://doi.org/10.1016/j.sbspro.2013.11.208

McNally, M. G. (2008). The Four-Step Model. In D. A. Hensher & K. J. Button (Eds.), *Handbook of Transport Modelling* (Second Edi, pp. 35–52). Elsevier Ltd. Retrieved from http://www.escholarship.org/uc/item/0r75311t

McNally, M. G., & Rindt, C. R. (2008). The Activity-Based Approach. In D. A. Hensher & K. J. Button (Eds.), *Handbook of Transport Modelling* (Second Edi, pp. 55–74). Elsevier L.

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. http://doi.org/10.1016/j.tra.2010.07.008

Milakis, D., & Athanasopoulos, K. (2014). What about people in cycle network planning? Applying participative multicriteria GIS analysis in the case of the Athens metropolitan cycle network. *Journal of Transport Geography*, *35*, 120–129. http://doi.org/10.1016/j.jtrangeo.2014.01.009

Miller, H. J. (2014). Activity-Based Analysis. In M. M. Fischer & P. Nijkamp (Eds.), *Handbook of Regional Science* (pp. 705–724). Springer-Verlag Berlin Heidelberg. http://doi.org/10.1007/978-3-642-23430-9

Neirotti, P., De Marco, A., Cagliano, A. C., Mangano, G., & Scorrano, F. (2014). Current trends in smart city initiatives: Some stylised facts. *Cities*, *38*, 25–36. http://doi.org/10.1016/j.cities.2013.12.010

Ortúzar, J. D. D., & Willumsen, L. G. (2011). *Modelling Transport* (Fourth Edi). John Wiley & Sons, Ltd. http://doi.org/10.1002/9781119993308

Papinski, D., Scott, D. M., & Doherty, S. T. (2009). Exploring the route choice decision-making process: A comparison of planned and observed routes obtained using person-based GPS. *Transportation Research Part F: Traffic Psychology and Behaviour*, *12*(4), 347–358. http://doi.org/10.1016/j.trf.2009.04.001

Parkin, J., Ryley, T., & Jones, T. (2007). Barriers to Cycling : An Exploration of Quantitative Analyses. *Civil Engineering: Book Chapters*, *Paper 1*, 67–82. Retrieved from http://digitalcommons.bolton.ac.uk/ce_chapters/1

Parking, J., Wardman, M. R., & Page, M. (2007). Models of Perceived Cycling Risk and Route Acceptability. *Accident Analysis and Prevention*, *39*(2), 364–371. http://doi.org/10.1016/j.aap.2006.08.007

Piatkowski, D. P., & Marshall, W. (2015). Not all prospective bicyclists are created equal: The role of attitudes, socio-demographics, and the built environment in bicycle commuting. *Travel Behaviour and Society*, (March). http://doi.org/10.1016/j.tbs.2015.02.001

Platform Beter Benutten. (2014). Bereikt in Mobiliteit. Retrieved from http://beterbenutten.nl/bereikt-in-mobiliteit

Pucher, J., & Buehler, R. (2008). Making Cycling Irresistible: Lessons from The Netherlands, Denmark and Germany. *Transport Reviews*, *28*(4), 495–528. http://doi.org/10.1080/01441640701806612

Pucher, J., Dill, J., & Handy, S. (2010). Infrastructure, programs, and policies to increase bicycling: An international review. *Preventive Medicine*, *50*(SUPPL.), S106–S125. http://doi.org/10.1016/j.ypmed.2009.07.028

Rasouli, S., & Timmermans, H. (2014). Activity-based models of travel demand: promises, progress and prospects. *International Journal of Urban Sciences*, *18*(1), 31–60. http://doi.org/10.1080/12265934.2013.835118

Rybarczyk, G., & Wu, C. (2010). Bicycle facility planning using GIS and multi-criteria decision analysis. *Applied Geography*, *30*(2), 282–293. http://doi.org/10.1016/j.apgeog.2009.08.005

Scheepers, C. E., Wendel-Vos, G. C. W., den Broeder, J. M., van Kempen, E. E. M. M., van Wesemael, P. J. V, & Schuit, A. J. (2014). Shifting from car to active transport: A systematic review of the effectiveness of interventions. *Transportation Research Part A: Policy and Practice*, *70*, 264–280. http://doi.org/10.1016/j.tra.2014.10.015

Scheepers, E., Wendel-Vos, W., van Kempen, E., Panis, L. I., Maas, J., Stipdonk, H., … Schuit, J. (2013). Personal and Environmental Characteristics Associated with Choice of Active Transport Modes versus Car Use for Different Trip Purposes of Trips up to 7.5 Kilometers in The Netherlands. *PLoS ONE*, *8*(9), 1–10. http://doi.org/10.1371/journal.pone.0073105

Schepers, J. P., & Heinen, E. (2013). How does a modal shift from short car trips to cycling affect road safety? *Accident Analysis and Prevention*, *50*, 1118–1127. http://doi.org/10.1016/j.aap.2012.09.004

Schepers, P., Hagenzieker, M., Methorst, R., van Wee, B., & Wegman, F. (2014). A conceptual framework for road safety and mobility applied to cycling safety. *Accident Analysis and Prevention*, *62*, 331–340. http://doi.org/10.1016/j.aap.2013.03.032

Schneider, R. J. (2013). Theory of routine mode choice decisions: An operational framework to increase sustainable transportation. *Transport Policy*, *25*, 128–137. http://doi.org/10.1016/j.tranpol.2012.10.007

Sener, I. N., Eluru, N., & Bhat, C. R. (2013). *An Analysis of Bicycle Route Choice Preferences Using a Web-Based Survey to Examine Bicycle Facilities*. Retrieved from http://www.caee.utexas.edu/prof/bhat/ABSTRACTS/Bicycle_sener_eluru_bhat_7April09.pdf

Spotswood, F., Chatterton, T., & Tapp, A. (2015). Analysing cycling as a social practice: An empirical grounding for behaviour change. *Transportation Research Part F: Psychology and Behaviour*, *29*, 22–33. http://doi.org/10.1016/j.trf.2014.12.001

Stinson, M. a, & Bhat, C. R. (2005). A comparison of the route preferences of experienced and inexperienced bicycle commuters. *Transportation Research Board 84th Annual Meeting*, (512).

Stinson, M., & Bhat, C. (2003). Commuter Bicyclist Route Choice: Analysis Using a Stated Preference Survey. *Transportation Research Record*, *1828*(1), 107–115. http://doi.org/10.3141/1828-13

St-Louis, E., Manaugh, K., van Lierop, D., & El-Geneidy, A. (2014). The happy commuter: A comparison of commuter satisfaction across modes. *Transportation Research Part F: Traffic Psychology and Behaviour*, *26*, 160–170. http://doi.org/10.1016/j.trf.2014.07.004

Suzuki, K., Kanda, Y., Doi, K., & Tsuchizaki, N. (2012). Proposal and Application of a New Method for Bicycle Network Planning. *Procedia - Social and Behavioral Sciences*, *43*(0), 558–570. http://doi.org/10.1016/j.sbspro.2012.04.129

Thomas, G. O., Walker, I., & Musselwhite, C. (2014). Grounded Theory analysis of commuters discussing a workplace carbon-reduction target: Autonomy, satisfaction, and willingness to change behaviour in drivers, pedestrians, bicyclists, motorcyclists, and bus users. *Transportation Research Part F: Traffic Psychology and Behaviour*, *26*, 72–81. http://doi.org/10.1016/j.trf.2014.06.009

Train, K. (2002). *Discrete Choice Methods with Simulation*. Cambridge University Press. http://doi.org/10.1017/CBO9780511753930

Van Boggelen, O., & Hengeveld, J. (2010). Gevoeligheidsanalyse effecten fietsbeleid. *Fietsberaad*, (Publicatie 18). Retrieved from http://www.fietsberaad.nl/?lang=nl&repository=Fietsberaadpublicatie+18+Gevoeligheidsanalyse+effecten+fietsbeleid

Van der Waerden, P., Borgers, A., & Timmermans, H. (2006). The Influence of Bicycle Path Characteristics on Cyclists ' Evaluation of Safety , Level of Comfort , and Circulation. *85th Annual Meeting of the Transportation Research Board on Bicycle Transportation*, 1–17.

Van der Waerden, P., & Timmermans, H. (2007). *Effects of Infrastructural Measures on Travelers' Willingness to Walk and Cycle*. *Proceedings of the 11th World Conference on Transportation Research*. Berkeley, USA.

Vanoutrive, T., Van Malderen, L., Jourquin, B., Thomas, I., Verhetsel, A., & Witlox, F. (2009). "Let the business cycle!" A spatial multilevel analysis of cycling to work. *Belgeo*, *2*. Retrieved from http://belgeo.revues.org/8763

Verkeerskunde. (2013). Uniek fietsverkeersmodel in de maak. Retrieved September 25, 2015, from http://verkeerskunde.nl/uniek-fietsverkeersmodel-in-de-maak.35029.lynkx

VogelvrijeFietser. (2014). Nederland heeft nog 675 kilometer fietssnelweg nodig, 20. Retrieved from http://www.fietssnelwegen.nl/Links/675 km Fietssnelwegen.pdf

Volkskrant. (2013). Fietsersbond zet 675 km aan nieuwe snelfietsroutes op ' Toekomstagenda ', (21 september). Retrieved from http://www.volkskrant.nl/dossier-archief/fietsersbond-zet-675-km-aan-nieuwe-snelfietsroutes-op-toekomstagenda~a3513602/

Wang, D., & Cheng, T. (2001). A spatio-temporal data model for activity-based transport demand modelling. *International Journal of Geographical Information Science*, *15*(6), 561–585. http://doi.org/10.1080/13658810110046934

Wardman, M., Tight, M., & Page, M. (2007). Factors influencing the propensity to cycle to work. *Transportation Research Part A: Policy and Practice*, *41*(4), 339–350. http://doi.org/10.1016/j.tra.2006.09.011

Wegener, M. (2014). Land-Use Transport Interaction Models. In M. M. Fischer & P. Nijkamp (Eds.), *Handbook of Regional Science* (pp. 741–758). Springer-Verlag Berlin Heidelberg. http://doi.org/10.1007/978-3-642-23430-9

Winters, M., Brauer, M., Setton, E. M., & Teschke, K. (2010). Built environment influences on healthy transportation choices: Bicycling versus driving. *Journal of Urban Health*, *87*(6), 969–993. http://doi.org/10.1007/s11524-010-9509-6

Winters, M., Davidson, G., Kao, D., & Teschke, K. (2011). Motivators and deterrents of bicycling: Comparing influences on decisions to ride. *Transportation*, *38*(1), 153–168. http://doi.org/10.1007/s11116-010-9284-y

Witlox, F., & Tindemans, H. (2004). The application of rough sets analysis in activity-based modelling. Opportunities and constraints. *Expert Systems with Applications*, *27*(4), 585–592. http://doi.org/10.1016/j.eswa.2004.06.003

Yagi, S., & Mohammadian, A. (2010). An activity-based microsimulation model of travel demand in the Jakarta metropolitan area. *Journal of Choice Modelling*, *3*(1), 32–57. http://doi.org/10.1016/S1755-5345(13)70028-9

Yang, C., & Mesbah, M. (2013). Route Choice Behaviour of Cyclists by Stated Preference and Revealed Preference. *Australasian Transport Research Forum 2013 Proceedings*, (October). Retrieved from http://atrf.info/papers/2013/2013_yang_mesbah.pdf

Appendices

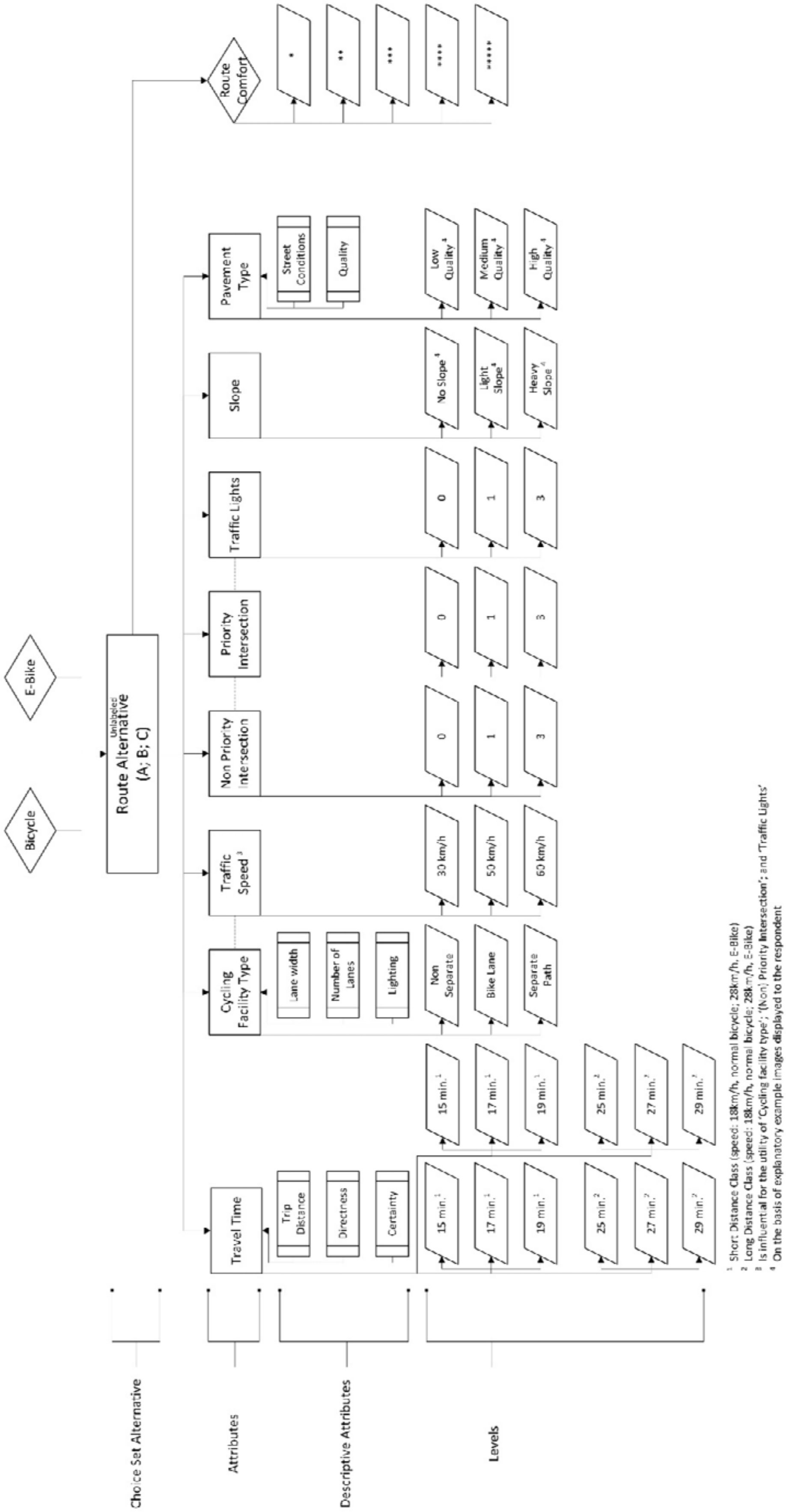
Appendix A: List of Influential Attributes

Attributes	*Influence on Bike-Use / Mode-Choice*	*Influence on Route-Choice*	*Ability To Be Influenced*
Trip purpose	+	+/-	-
Demographic factors			
Gender	+/-	+/-	-
Age	+	+	-
Education level	+	-	-
Household composition	+	-	-
Housing type	-	-	-
Employment	+	+	-
Income	+	-	-
Health	+	+	-
Marital status	-	-	-
Social cultural factors			
Overall life satisfaction	+/-	-	-
Traffic education	+	+	+/-
Health consciousness	+	+/-	+/-
Habit	+	+	+/-
Bike use frequency	+	+/-	+/-
Spatial economic factors			
Trip origin	+	+	-
Trip destination	+	+	-
Time of day or night	+	+	-
Neighborhood typology	+	+/-	-
Land-use diversity	+	+	+/-
Work schedule flexibility	+	+/-	-
Physical factors			
Weather	+	-	-
Natural barriers	+	+	-
Traffic and transportation factors			
Mobility difficulties	+	-	-
Driving license possession	+	-	-
Car ownership	+	-	-
Public transport pass ownership	+	+/-	-
Bicycle ownership	+	-	-
Distance	+	+	-
Trip costs	+	-	+/-
Mode experience	+	+/-	-
Route topography	+	+	+/-
Congestion	+	+	+/-
Parking availability	+	+/-	+
Security	+	+	+
Quality of infrastructure	+	+	+
Directness	+/-	+	+
Attitudes towards mode	+	-	+/-
Perception of comfort	+	+	-

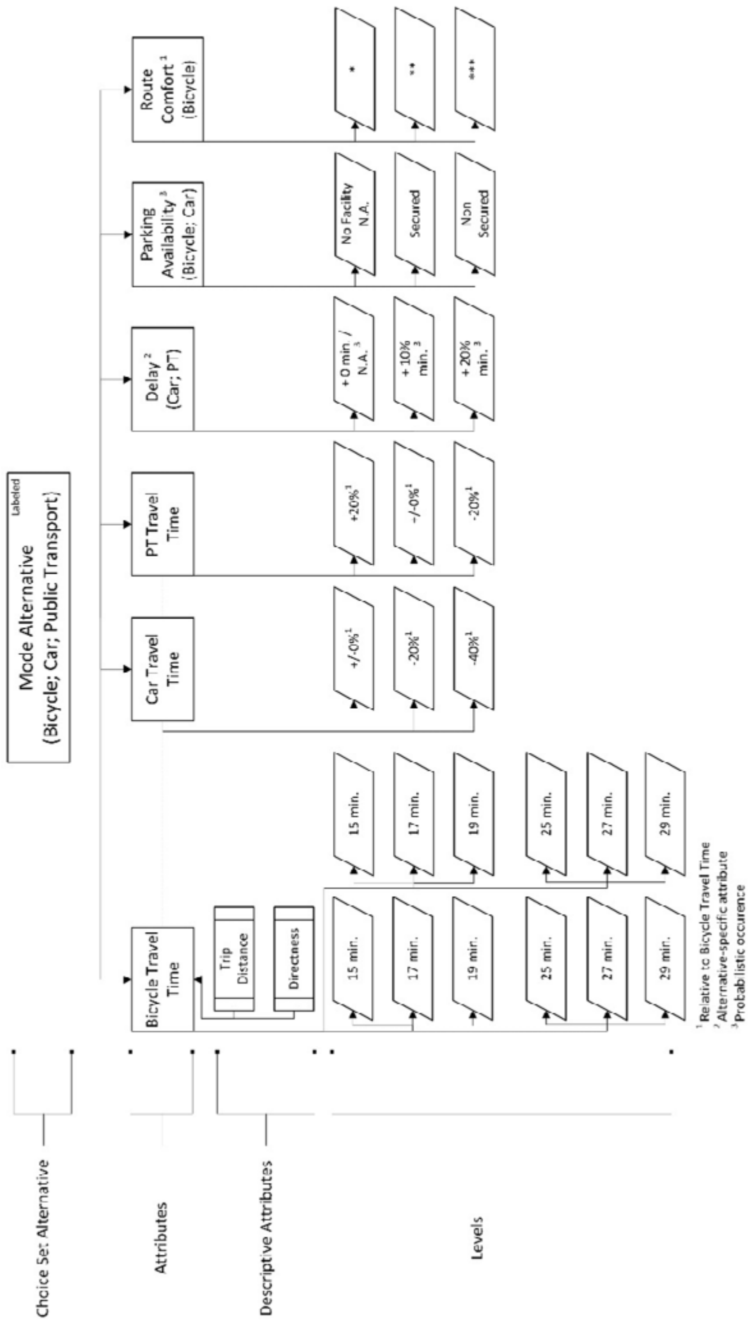
Perception of safety	+	+	-
Travel time	+	+	+/-
Travel time certainty	+	+	+/-
Personal trip experience	+	+	-
Quality of scenery	+/-	+	+/-
Access to facilities	+	+	+
<u>Specific comfort and safety aspects</u>			
Number of bike lanes	+	+	+
Number of connections between lanes / paths	+	+	+
Perception of road safety	+	+	+
Street conditions	+	+	+
Lighting on facilities	+	+	+
Bike Storage	+	+	+
Quality of the bike	+	-	-
Access of bike on transit	+	+/-	+/-
Amount of cargo to carry	+	+/-	-
Slope	+	+	+/-
Separate cycling facilities	+	+	+/-
Intersection modifications / priority	+	+	+
Traffic speed	+	+	+
Traffic intensity	+	+	+/-
Junction density	+	+	+/-
Number of stops	+	+	+
Bicycle lane width	+/-	+	+
Facilities on destination	+	+	+/-
Legibility	-	+	+
Travel companions	+	+	-

+ = easily being influenced / high influence; +/-= hard to be influenced / hardly influence; - = not able to be influenced / no influence;

Appendix B: Route-Choice Attributes and Levels



Appendix C: Mode-Choice Attributes and Levels



Appendix D: Treatment Combinations

Treatment combinations for 'short distance' class, route-choice experiment

	Priority	*Facility type*	*Non Priority*	*Traffic Lights*	*Pavement Quality*	*Travel Time*	*Traffic Speed*	*Slope*	*Score 0 – 1 - 2*
1	No Intersections	Bicycle Path	Three Intersections	Three Intersections	Medium Quality	15 minutes	50 km/h	No Slope	10
2	No Intersections	Bicycle Path	One Intersection	One Intersection	Low Quality	17 minutes	60 km/h	Two Slopes	7
3	No Intersections	Bicycle Path	No Intersections	No Intersections	High Quality	19 minutes	30 km/h	One Slope	**13**
4	No Intersections	No Facility	Three Intersections	Three Intersections	Low Quality	19 minutes	30 km/h	Two Slopes	**4**
5	No Intersections	No Facility	One Intersection	One Intersection	High Quality	15 minutes	50 km/h	One Slope	10
6	No Intersections	No Facility	No Intersections	No Intersections	Medium Quality	17 minutes	60 km/h	No Slope	10
7	No Intersections	Bicycle Lane	Three Intersections	Three Intersections	High Quality	17 minutes	60 km/h	One Slope	7
8	No Intersections	Bicycle Lane	One Intersection	One Intersection	Medium Quality	19 minutes	30 km/h	No Slope	10
9	No Intersections	Bicycle Lane	No Intersections	No Intersections	Low Quality	15 minutes	50 km/h	Two Slopes	10
10	One Intersection	Bicycle Path	Three Intersections	One Intersection	Low Quality	19 minutes	60 km/h	One Slope	**5**
11	One Intersection	Bicycle Path	One Intersection	No Intersections	High Quality	15 minutes	30 km/h	No Slope	**14**
12	One Intersection	Bicycle Path	No Intersections	Three Intersections	Medium Quality	17 minutes	50 km/h	Two Slopes	8
13	One Intersection	No Facility	Three Intersections	One Intersection	High Quality	17 minutes	50 km/h	No Slope	8
14	One Intersection	No Facility	One Intersection	No Intersections	Medium Quality	19 minutes	60 km/h	Two Slopes	**5**
15	One Intersection	No Facility	No Intersections	Three Intersections	Low Quality	15 minutes	30 km/h	One Slope	8
16	One Intersection	Bicycle Lane	Three Intersections	One Intersection	Medium Quality	15 minutes	30 km/h	Two Slopes	8
17	One Intersection	Bicycle Lane	One Intersection	No Intersections	Low Quality	17 minutes	50 km/h	One Slope	8
18	One Intersection	Bicycle Lane	No Intersections	Three Intersections	High Quality	19 minutes	60 km/h	No Slope	8
19	Three Intersections	Bicycle Path	Three Intersections	No Intersections	High Quality	17 minutes	30 km/h	Two Slopes	9
20	Three Intersections	Bicycle Path	One Intersection	Three Intersections	Medium Quality	19 minutes	50 km/h	One Slope	6
21	Three Intersections	Bicycle Path	No Intersections	One Intersection	Low Quality	15 minutes	60 km/h	No Slope	9
22	Three Intersections	No Facility	Three Intersections	No Intersections	Medium Quality	15 minutes	60 km/h	One Slope	6
23	Three Intersections	No Facility	One Intersection	Three Intersections	Low Quality	17 minutes	30 km/h	No Slope	6
24	Three Intersections	No Facility	No Intersections	One Intersection	High Quality	19 minutes	50 km/h	Two Slopes	6
25	Three Intersections	Bicycle Lane	Three Intersections	No Intersections	Low Quality	19 minutes	50 km/h	No Slope	6
26	Three Intersections	Bicycle Lane	One Intersection	Three Intersections	High Quality	15 minutes	60 km/h	Two Slopes	6
27	Three Intersections	Bicycle Lane	No Intersections	One Intersection	Medium Quality	17 minutes	30 km/h	One Slope	9

Treatment combinations for ‘long distance’ class, route-choice experiment

	Priority	*Facility type*	*Non Priority*	*Traffic Lights*	*Pavement Quality*	*Travel Time*	*Traffic Speed*	*Slope*	*Score 0 – 1 - 2*
1	No Intersections	Bicycle Path	Three Intersections	Three Intersections	Medium Quality	25 minutes	50 km/h	No Slope	10
2	No Intersections	Bicycle Path	One Intersection	One Intersection	Low Quality	27 minutes	60 km/h	Two Slopes	7
3	No Intersections	Bicycle Path	No Intersections	No Intersections	High Quality	29 minutes	30 km/h	One Slope	**13**
4	No Intersections	No Facility	Three Intersections	Three Intersections	Low Quality	29 minutes	30 km/h	Two Slopes	**4**
5	No Intersections	No Facility	One Intersection	One Intersection	High Quality	25 minutes	50 km/h	One Slope	10
6	No Intersections	No Facility	No Intersections	No Intersections	Medium Quality	27 minutes	60 km/h	No Slope	10
7	No Intersections	Bicycle Lane	Three Intersections	Three Intersections	High Quality	27 minutes	60 km/h	One Slope	7
8	No Intersections	Bicycle Lane	One Intersection	One Intersection	Medium Quality	29 minutes	30 km/h	No Slope	10
9	No Intersections	Bicycle Lane	No Intersections	No Intersections	Low Quality	25 minutes	50 km/h	Two Slopes	10
10	One Intersection	Bicycle Path	Three Intersections	One Intersection	Low Quality	29 minutes	60 km/h	One Slope	**5**
11	One Intersection	Bicycle Path	One Intersection	No Intersections	High Quality	25 minutes	30 km/h	No Slope	**14**
12	One Intersection	Bicycle Path	No Intersections	Three Intersections	Medium Quality	27 minutes	50 km/h	Two Slopes	8
13	One Intersection	No Facility	Three Intersections	One Intersection	High Quality	27 minutes	50 km/h	No Slope	8
14	One Intersection	No Facility	One Intersection	No Intersections	Medium Quality	29 minutes	60 km/h	Two Slopes	**5**
15	One Intersection	No Facility	No Intersections	Three Intersections	Low Quality	25 minutes	30 km/h	One Slope	8
16	One Intersection	Bicycle Lane	Three Intersections	One Intersection	Medium Quality	25 minutes	30 km/h	Two Slopes	8
17	One Intersection	Bicycle Lane	One Intersection	No Intersections	Low Quality	27 minutes	50 km/h	One Slope	8
18	One Intersection	Bicycle Lane	No Intersections	Three Intersections	High Quality	29 minutes	60 km/h	No Slope	8
19	Three Intersections	Bicycle Path	Three Intersections	No Intersections	High Quality	27 minutes	30 km/h	Two Slopes	9
20	Three Intersections	Bicycle Path	One Intersection	Three Intersections	Medium Quality	29 minutes	50 km/h	One Slope	6
21	Three Intersections	Bicycle Path	No Intersections	One Intersection	Low Quality	25 minutes	60 km/h	No Slope	9
22	Three Intersections	No Facility	Three Intersections	No Intersections	Medium Quality	25 minutes	60 km/h	One Slope	6
23	Three Intersections	No Facility	One Intersection	Three Intersections	Low Quality	27 minutes	30 km/h	No Slope	6
24	Three Intersections	No Facility	No Intersections	One Intersection	High Quality	29 minutes	50 km/h	Two Slopes	6
25	Three Intersections	Bicycle Lane	Three Intersections	No Intersections	Low Quality	29 minutes	50 km/h	No Slope	6
26	Three Intersections	Bicycle Lane	One Intersection	Three Intersections	High Quality	25 minutes	60 km/h	Two Slopes	6
27	Three Intersections	Bicycle Lane	No Intersections	One Intersection	Medium Quality	27 minutes	30 km/h	One Slope	9

Treatment combinations for 'short distance' class, mode-choice experiment

	Bicycle Travel Time	*Bicycle Parking*	*Route-Comfort*	*Car Travel Time*	*Car Delay*	*Car Parking*	*PT Travel Time*	*PT Delay*	*Score 0 – 1 - 2*
1	15 minutes	Secured Facility	*	-0% minutes	+10% minutes	Secured Facility	+/-0% minutes	+0% minutes	10
2	15 minutes	Secured Facility	***	-20% minutes	+20% minutes	Non Secured Facility	+20% minutes	+20% minutes	7
3	15 minutes	Secured Facility	*****	-40% minutes	+0% minutes	No Facility	-20% minutes	+10% minutes	**13**
4	15 minutes	No Facility	*	-0% minutes	+20% minutes	No Facility	-20% minutes	+20% minutes	**4**
5	15 minutes	No Facility	***	-20% minutes	+0% minutes	Secured Facility	+/-0% minutes	+10% minutes	10
6	15 minutes	No Facility	*****	-40% minutes	+10% minutes	Non Secured Facility	+20% minutes	+0% minutes	10
7	15 minutes	Non Secured Facility	*	-0% minutes	+0% minutes	Non Secured Facility	+20% minutes	+10% minutes	7
8	15 minutes	Non Secured Facility	***	-20% minutes	+10% minutes	No Facility	-20% minutes	+0% minutes	10
9	15 minutes	Non Secured Facility	*****	-40% minutes	+20% minutes	Secured Facility	+/-0% minutes	+20% minutes	10
10	17 minutes	Secured Facility	*	-20% minutes	+20% minutes	No Facility	+20% minutes	+10% minutes	**5**
11	17 minutes	Secured Facility	***	-40% minutes	+0% minutes	Secured Facility	-20% minutes	+0% minutes	**14**
12	17 minutes	Secured Facility	*****	-0% minutes	+10% minutes	Non Secured Facility	+/-0% minutes	+20% minutes	8
13	17 minutes	No Facility	*	-20% minutes	+0% minutes	Non Secured Facility	+/-0% minutes	+0% minutes	8
14	17 minutes	No Facility	***	-40% minutes	+10% minutes	No Facility	+20% minutes	+20% minutes	**5**
15	17 minutes	No Facility	*****	-0% minutes	+20% minutes	Secured Facility	-20% minutes	+10% minutes	8
16	17 minutes	Non Secured Facility	*	-20% minutes	+10% minutes	Secured Facility	-20% minutes	+20% minutes	8
17	17 minutes	Non Secured Facility	***	-40% minutes	+20% minutes	Non Secured Facility	+/-0% minutes	+10% minutes	8
18	17 minutes	Non Secured Facility	*****	-0% minutes	+0% minutes	No Facility	+20% minutes	+0% minutes	8
19	19 minutes	Secured Facility	*	-40% minutes	+0% minutes	Non Secured Facility	-20% minutes	+20% minutes	9
20	19 minutes	Secured Facility	***	-0% minutes	+10% minutes	No Facility	+/-0% minutes	+10% minutes	6
21	19 minutes	Secured Facility	*****	-20% minutes	+20% minutes	Secured Facility	+20% minutes	+0% minutes	9
22	19 minutes	No Facility	*	-40% minutes	+10% minutes	Secured Facility	+20% minutes	+10% minutes	6
23	19 minutes	No Facility	***	-0% minutes	+20% minutes	Non Secured Facility	-20% minutes	+0% minutes	6
24	19 minutes	No Facility	*****	-20% minutes	+0% minutes	No Facility	+/-0% minutes	+20% minutes	6
25	19 minutes	Non Secured Facility	*	-40% minutes	+20% minutes	No Facility	+/-0% minutes	+0% minutes	6
26	19 minutes	Non Secured Facility	***	-0% minutes	+0% minutes	Secured Facility	+20% minutes	+20% minutes	6
27	19 minutes	Non Secured Facility	*****	-20% minutes	+10% minutes	Non Secured Facility	-20% minutes	+10% minutes	9

Treatment combinations for 'long distance' class, mode-choice experiment

	Bicycle Travel Time	*Bicycle Parking*	*Route-Comfort*	*Car Travel Time*	*Car Delay*	*Car Parking*	*PT Travel Time*	*PT Delay*	*Score 0 – 1 - 2*
1	25 minutes	Secured Facility	*	-0% minutes	+10% minutes	Secured Facility	+/-0% minutes	+0% minutes	10
2	25 minutes	Secured Facility	***	-20% minutes	+20% minutes	Non Secured Facility	+20% minutes	+20% minutes	7
3	25 minutes	Secured Facility	*****	-40% minutes	+0% minutes	No Facility	-20% minutes	+10% minutes	**13**
4	25 minutes	No Facility	*	-0% minutes	+20% minutes	No Facility	-20% minutes	+20% minutes	**4**
5	25 minutes	No Facility	***	-20% minutes	+0% minutes	Secured Facility	+/-0% minutes	+10% minutes	10
6	25 minutes	No Facility	*****	-40% minutes	+10% minutes	Non Secured Facility	+20% minutes	+0% minutes	10
7	25 minutes	Non Secured Facility	*	-0% minutes	+0% minutes	Non Secured Facility	+20% minutes	+10% minutes	7
8	25 minutes	Non Secured Facility	***	-20% minutes	+10% minutes	No Facility	-20% minutes	+0% minutes	10
9	25 minutes	Non Secured Facility	*****	-40% minutes	+20% minutes	Secured Facility	+/-0% minutes	+20% minutes	10
10	27 minutes	Secured Facility	*	-20% minutes	+20% minutes	No Facility	+20% minutes	+10% minutes	**5**
11	27 minutes	Secured Facility	***	-40% minutes	+0% minutes	Secured Facility	-20% minutes	+0% minutes	**14**
12	27 minutes	Secured Facility	*****	-0% minutes	+10% minutes	Non Secured Facility	+/-0% minutes	+20% minutes	8
13	27 minutes	No Facility	*	-20% minutes	+0% minutes	Non Secured Facility	+/-0% minutes	+0% minutes	8
14	27 minutes	No Facility	***	-40% minutes	+10% minutes	No Facility	+20% minutes	+20% minutes	**5**
15	27 minutes	No Facility	*****	-0% minutes	+20% minutes	Secured Facility	-20% minutes	+10% minutes	8
16	27 minutes	Non Secured Facility	*	-20% minutes	+10% minutes	Secured Facility	-20% minutes	+20% minutes	8
17	27 minutes	Non Secured Facility	***	-40% minutes	+20% minutes	Non Secured Facility	+/-0% minutes	+10% minutes	8
18	27 minutes	Non Secured Facility	*****	-0% minutes	+0% minutes	No Facility	+20% minutes	+0% minutes	8
19	29 minutes	Secured Facility	*	-40% minutes	+0% minutes	Non Secured Facility	-20% minutes	+20% minutes	9
20	29 minutes	Secured Facility	***	-0% minutes	+10% minutes	No Facility	+/-0% minutes	+10% minutes	6
21	29 minutes	Secured Facility	*****	-20% minutes	+20% minutes	Secured Facility	+20% minutes	+0% minutes	9
22	29 minutes	No Facility	*	-40% minutes	+10% minutes	Secured Facility	+20% minutes	+10% minutes	6
23	29 minutes	No Facility	***	-0% minutes	+20% minutes	Non Secured Facility	-20% minutes	+0% minutes	6
24	29 minutes	No Facility	*****	-20% minutes	+0% minutes	No Facility	+/-0% minutes	+20% minutes	6
25	29 minutes	Non Secured Facility	*	-40% minutes	+20% minutes	No Facility	+/-0% minutes	+0% minutes	6
26	29 minutes	Non Secured Facility	***	-0% minutes	+0% minutes	Secured Facility	+20% minutes	+20% minutes	6
27	29 minutes	Non Secured Facility	*****	-20% minutes	+10% minutes	Non Secured Facility	-20% minutes	+10% minutes	9

Appendix E: Example Online Questionnaire (Dutch)

Technische Universiteit Eindhoven University of Technology

Royal HaskoningDHV Enhancing Society Together

Fietsgedrag, route-keuze en vervoerswijzen

Beste meneer / mevrouw,

Deze enquête is opgesteld voor een afstudeeronderzoek aan de Technische Universiteit Eindhoven. Het onderzoek is bedoeld om meer inzicht te krijgen in gedrag van fietsers en hun routekeuze.

Door het invullen van deze vragenlijst draagt u bij aan mijn onderzoek en daar wil ik u alvast hartelijk voor bedanken.

Uw antwoorden worden uiteraard anoniem verwerkt. De invulduur bedraagt 10-15 minuten.

Met vriendelijke groet,

Rens van Overdijk

Start Enquête

Berg Enquête System 2 © 2007-2015 Design Systems

Technische Universiteit Eindhoven University of Technology

Royal HaskoningDHV Enhancing Society Together

Fietsgedrag, route-keuze en vervoerswijzen

Welke van onderstaande type fietsen gebruikt u over het algemeen?

Geef aan welk type fiets u het vaakst gebruikt.

- Normale fiets (ook racefiets of mountainbike)
- E-Bike (ook speed-pedelec)
- Ik fiets nooit

Vorige Volgende

Berg Enquête System 2 © 2007-2015 Design Systems

TU/e Technische Universiteit Eindhoven University of Technology

Royal HaskoningDHV Enhancing Society Together

Fietsgedrag, route-keuze en vervoerswijzen

Welke afstand legt u over het algemeen af met de fiets voor een enkele rit met de volgende doeleinden?

Doeleinden	Nooit	Tot 3 km	3,1 - 5 km	5,1 - 7,5 km	7,6 - 10 km	Meer dan 10 km
Van huis naar winkels	○	●	○	○	○	○
Van huis naar werk / studie	○	○	●	○	○	○
Van huis naar sport, muziekles, ontspanning, etc.	○	●	○	○	○	○
Familie en vrienden bezoeken	○	○	●	○	○	○

Vorige Volgende

Hoe vaak heeft u een auto ter beschikking?

○ Altijd
● Soms
○ Nooit

Beschikt u over een Openbaar Vervoer (OV)-kaart?

○ Nee
○ Ja, zonder abonnement
○ Ja, met kortingsabonnement
● Ja, met gratis reizen abonnement
○ Ja, anders namelijk:

Als u met de trein ergens naar toe gaat, hoe vaak fietst u dan naar het station?

○ Altijd
● Soms
○ Nooit
○ Ik ga nooit met de trein

Als u met de bus ergens naar toe gaat, hoe vaak fietst u dan naar de halte?

● Altijd
○ Soms
○ Nooit
○ Ik ga nooit met de bus

Vorige Volgende

Technische Universiteit **Eindhoven** University of Technology

Royal HaskoningDHV *Enhancing Society Together*

Fietsgedrag, route-keuze en vervoerswijzen

Hoe vaak maakt u voor onderstaande doeleinden gebruik van de volgende vervoermiddelen voor het grootste deel van de rit?

U dient hier overal iets in te vullen.

Doeleinden	Fiets / E-Bike	Auto	Openbaar Vervoer
Van huis naar winkels	1 - 3 keer per week	1 - 3 keer per week	Minder dan 1 keer per maand
Van huis naar werk / studie	Minder dan 1 keer per maand	1 - 3 keer per maand	4 - 5 keer per week
Van huis naar sport, muziekles, ontspanning, etc.	1 - 3 keer per week	Nooit	Nooit
Familie en vrienden bezoeken	1 - 3 keer per week	1 - 3 keer per maand	Nooit

Vorige **Volgende**

Berg Enquête System 2 © 2007-2015 Design Systems

In welke mate zijn onderstaande factoren bepalend om te fietsen?

Motivatie	Wel	Enigszins	Niet	Geen Mening
Financieel voordeel	●	○	○	○
Het milieu	○	●	○	○
Angst voor autorijden	○	○	●	○
Goed voor de gezondheid	●	○	○	○
Geen rijbewijs	○	○	○	●
Gebruiksgemak	○	●	○	○
Anders, namelijk:*	○	○	○	○

**Optioneel*

Vorige **Volgende**

Berg Enquête System 2 © 2007-2015 Design Systems

Fietsgedrag, route-keuze en vervoerswijzen

In welke mate herkent u zich in onderstaand gedrag?

Stelling	Volledig mee eens	Mee eens	Mee oneens	Volledig mee oneens	Niet van toepassing
Ik fiets nooit door rood licht.	○	●	○	○	○
Ik fiets nooit tegen de richting in.	○	○	●	○	○
Ik probeer routes met langs de weg geparkeerde auto's zoveel mogelijk te mijden.	○	○	○	●	○
Ik mijd 'onveilige' routes.	○	●	○	○	○
Ik pas mijn route aan wanneer ik met kinderen samen fiets.	●	○	○	○	○
Ik pas mijn route aan voor een mooiere omgeving / route-beleving.	○	●	○	○	○

Vorige **Volgende**

Fietsgedrag, route-keuze en vervoerswijzen

In dit onderdeel gaan we ervan uit dat u een rit gaat maken met de **Fiets**. We vragen u nu een aantal keren te kiezen tussen twee routes. De routes omschrijven een rit **van huis naar werk of studie**. U mag ervan uitgaan dat de rit **overdag** plaatsvindt bij **heldere en droge weersomstandigheden en weinig wind.** Daarnaast mag u ervan uitgaan dat u **alleen fietst** en dat u **geen zware bagage** bij u heeft tijdens de rit.

De routes hebben verschillende kenmerken. Deze worden eerst verder toegelicht:

Vorige **Volgende**

Fietsgedrag, route-keuze en vervoerswijzen

Reistijd: De tijd die u kwijt bent via de desbetreffende route. _Hier zijn mogelijke wachttijden bij kruispunten niet meegerekend._

Fietsvoorziening: Hiermee wordt bedoeld wat voor type fietspad op het grootste deel van de route aanwezig is. U mag uitgaan van onderstaande voorbeelden:

Vrijliggend Fietspad:

Fietsstrook:

Geen Fietspad of Fietsstrook:

Vorige | Volgende

Technische Universiteit Eindhoven University of Technology

Royal HaskoningDHV Enhancing Society Together

Fietsgedrag, route-keuze en vervoerswijzen

Kwaliteit Wegdek: De kwaliteit van het wegdek hangt af van hoe vlak het wegdek is. De volgende voorbeelden geven een beeld van hoge, gemiddelde en lage kwaliteit:

Hoge Kwaliteit:

Gemiddelde Kwaliteit:

Lage Kwaliteit:

Vorige **Volgende**

Technische Universiteit Eindhoven University of Technology

Royal HaskoningDHV Enhancing Society Together

Fietsgedrag, route-keuze en vervoerswijzen

Snelheid Autoverkeer: Hiermee wordt de snelheid bedoeld van het overige verkeer op de weg. In het experiment worden situaties voorgelegd waarin 30 km/u, 50 km/u en 60 km/u wordt gereden door het langsrijdende autoverkeer.

Kruispunten: Met onderstaande symbolen wordt aangetoond wat voor type kruispunt(en) u op uw route tegenkomt. Het aantal symbolen geeft aan hoeveel kruispunten van dat type u tegenkomt. *Geen symbolen betekent dus geen kruispunten!*

Voorrang:	Bij dit kruispunt krijgt u voorrang.
Geen Voorrang:	Bij dit kruispunt moet u voorrang verlenen.
Verkeerslicht:	Bij dit kruispunt zijn verkeerslichten van toepassing.

Helling: Als laatste route-kenmerk kan het voorkomen dat er geen, één of twee hellingen aanwezig zijn op de route. Het aantal symbolen geeft aan hoeveel hellingen op de route aanwezig zijn. *Geen symbolen betekent dus geen hellingen!*

Helling: Dit bord geeft aan dat er een helling op de route aanwezig is. Hierbij moet u denken aan een viaduct waar u overheen moet, een fietstunnel, een heuvel, etc.

Route Comfort: Naast de vraag om te kiezen tussen twee routes wordt u ook gevraagd om een waardering te geven voor de kwaliteit van de desbetreffende routes. Dit doet u aan de hand van vijf sterren:

*	*Één ster:*	U vindt dit een route met een laag comfort.
**	*Twee sterren:*	U vindt dit een route met een onder gemiddeld comfort.
***	*Drie Sterren:*	U vindt dit een route met een gemiddeld comfort.
****	*Vier Sterren:*	U vindt dit een route met een boven gemiddeld comfort.
*****	*Vijf Sterren:*	U vindt dit een route met een hoog comfort.

Vorige Volgende

TU/e Technische Universiteit Eindhoven University of Technology

Royal HaskoningDHV Enhancing Society Together

Fietsgedrag, route-keuze en vervoerswijzen

VOORBEELDVRAAG

Nu volgt eerst een voorbeeldvraag. Onderstaande tabel omschrijft twee routes met de kenmerken die zojuist zijn uitgelegd. U wordt steeds gevraagd om iedere route te waarderen en om één route te kiezen waar uw voorkeur naar uit gaat.

Welke route kiest u?

Route Kenmerken	**Route A**	**Route B**
Reistijd	***17 minuten***	***15 minuten***
Fietsvoorziening	***Vrijliggend Fietspad***	***Geen Fietspad of Fietsstrook***
Snelheid Autoverkeer	60	50
Wegdek Kwaliteit	***Hoge Kwaliteit***	***Gemiddelde Kwaliteit***
Kruispunten[1]		
Helling[1]		
Welke route kiest u?		
Hoe waardeert u het comfort van route A en B? *(Laat hierbij de reistijd buiten beschouwing)*	****	**

[1] Het aantal symbolen geeft het aantal kruispunten of hellingen weer.

Vorige | **Volgende**

TU/e Technische Universiteit Eindhoven University of Technology

Royal HaskoningDHV Enhancing Society Together

Fietsgedrag, route-keuze en vervoerswijzen

In het volgende onderdeel wordt u gevraagd om een vervoerswijzekeuze te maken. Hier zijn enkele nieuwe kenmerken van toepassing. Deze worden nader toegelicht. U mag ervan uitgaan dat u in alle gevallen de beschikking heeft tot de **fiets**, **auto** en het **openbaar vervoer**. Daarnaast mag u er weer van uitgaan dat de rit **van huis naar werk of studie** **overdag** plaatsvindt bij **heldere en droge weersomstandigheden en weinig wind.** Ook mag u er verder van uitgaan dat u **alleen reist** en dat u **geen zware bagage** bij u heeft tijdens de rit.

Vorige | **Volgende**

Technische Universiteit Eindhoven University of Technology

Royal HaskoningDHV Enhancing Society Together

Fietsgedrag, route-keuze en vervoerswijzen

Reistijd: Naast een reistijd voor de fiets, is er nu ook een reistijd voor de auto en het openbaar vervoer.

Vertraging: Voor de auto bestaat een vertraging door mogelijke files. Ook voor het openbaar vervoer zijn er vertragingen mogelijk.

Parkeervoorziening: Hier wordt voor de auto en fiets aangegeven of er een specifieke voorziening aanwezig is:

Geen Parkeervoorziening:	In dit geval is er geen sprake van fietsenrekken, stallingen, etc. In het geval van de auto is er geen specifieke parkeerplaats, maar slechts een mogelijkheid tot parkeren langs de weg.
Onbewaakte Parkeervoorziening:	In dit geval is er sprake van een **gratis** fietsenstalling of fietsenrek zonder toezicht of een parkeerplaats voor auto's zonder toezicht.
Bewaakte Parkeervoorziening:	In dit geval is er sprake van een **gratis** fietsenstalling of parkeerplaats voor auto's die bewaakt is of onder toezicht staat.

Route-Comfort: Hier komt het aspect route-comfort terug uit het routekeuze onderdeel. Het route-comfort omschrijft het comfort van de aanwezige fietsroute. Een onderscheid wordt gemaakt in één, drie en vijf sterren voor respectieveleijk een laag, gemiddeld en hoog comfort.
U wordt verzocht uit te gaan van uw eigen mening over 'comfort' zoals u die heeft toegekend tijdens het route-keuze onderdeel.

Vorige | **Volgende**

Berg Enquête System 2 © 2007-2015 Design Systems

Nu volgt weer eerst een voorbeeldvraag. Onderstaande tabel omschrijft de kenmerken die zojuist zijn uitgelegd. U wordt steeds gevraagd om een vervoermiddel te kiezen waar uw voorkeur naar uit gaat.

Welk vervoermiddel kiest u?

Vervoermiddel	**Fiets / E-Bike**	**Auto**	**Openbaar Vervoer**
Reistijd	*15 minuten*	*12 minuten*	*18 minuten*
Vertraging		*+1½ minuut*	*+3 minuten*
Parkeervoorziening	*Bewaakt*	*Onbewaakt*	
Route-Comfort	***		
Welk vervoermiddel kiest u?	◉	○	○

Vorige | **Volgende**

Berg Enquête System 2 © 2007-2015 Design Systems

Technische Universiteit **Eindhoven** University of Technology

Royal HaskoningDHV *Enhancing Society Together*

Fietsgedrag, route-keuze en vervoerswijzen

Wat is uw geslacht?

- (•) Man
- ( ) Vrouw

Wat is uw leeftijd?

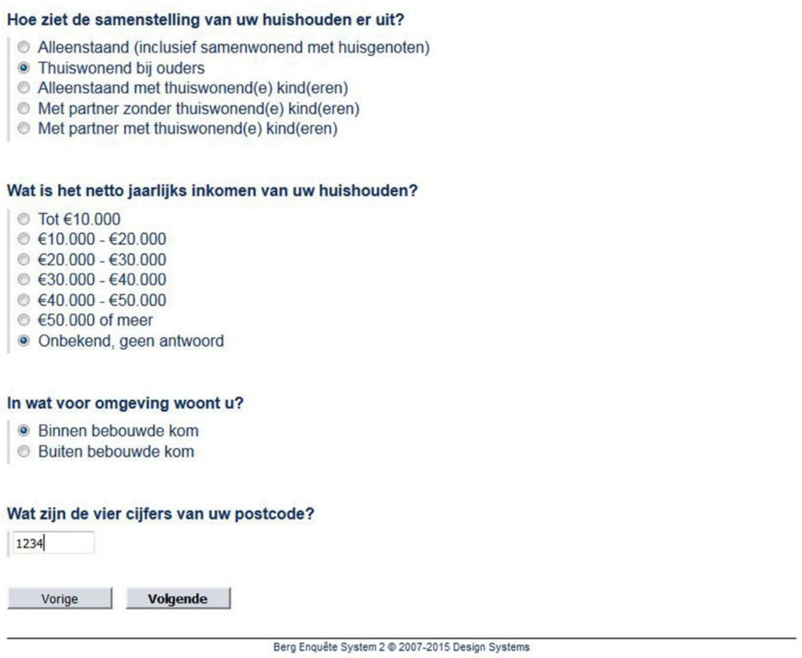
21 - 35 jaar

Wat is uw hoogst behaalde opleiding?

- ( ) Lager-of basisonderwijs
- ( ) Voortgezet onderwijs
- ( ) Middelbaar beroepsonderwijs (MBO)
- ( ) Hoger beroepsonderwijs (HBO)
- (•) Wetenschappelijk onderwijs (WO)
- ( ) Anders

Vorige | **Volgende**

Berg Enquête System 2 © 2007-2015 Design Systems



Hoe ziet de samenstelling van uw huishouden er uit?

- ( ) Alleenstaand (inclusief samenwonend met huisgenoten)
- (•) Thuiswonend bij ouders
- ( ) Alleenstaand met thuiswonend(e) kind(eren)
- ( ) Met partner zonder thuiswonend(e) kind(eren)
- ( ) Met partner met thuiswonend(e) kind(eren)

Wat is het netto jaarlijks inkomen van uw huishouden?

- ( ) Tot €10.000
- ( ) €10.000 - €20.000
- ( ) €20.000 - €30.000
- ( ) €30.000 - €40.000
- ( ) €40.000 - €50.000
- ( ) €50.000 of meer
- (•) Onbekend, geen antwoord

In wat voor omgeving woont u?

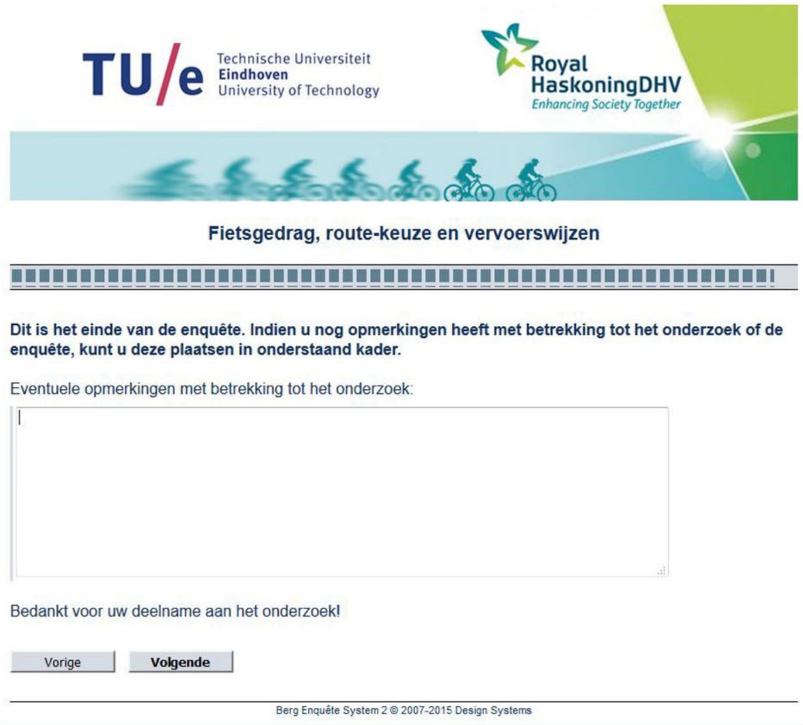
- (•) Binnen bebouwde kom
- ( ) Buiten bebouwde kom

Wat zijn de vier cijfers van uw postcode?

1234

Vorige | **Volgende**

Berg Enquête System 2 © 2007-2015 Design Systems



Technische Universiteit
Eindhoven
University of Technology

Royal
HaskoningDHV
Enhancing Society Together

Fietsgedrag, route-keuze en vervoerswijzen

Dit is het einde van de enquête. Indien u nog opmerkingen heeft met betrekking tot het onderzoek of de enquête, kunt u deze plaatsen in onderstaand kader.

Eventuele opmerkingen met betrekking tot het onderzoek:

Bedankt voor uw deelname aan het onderzoek!

Vorige **Volgende**

Berg Enquête System 2 © 2007-2015 Design Systems

This page intentionally left blank.

Appendix F: Behavioral Statements: SPSS Output

"I Do Never Run Red Lights"

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Totally Agree	292	40,1	40,1	40,1
	Agree	232	31,9	31,9	72,0
	Disagree	171	23,5	23,5	95,5
	Totally Disagree	23	3,2	3,2	98,6
	Not Applicable	10	1,4	1,4	100,0
	Total	728	100,0	100,0	

"I Do Never Cycle in the Wrong Direction"

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Totally Agree	236	32,4	32,4	32,4
	Agree	244	33,5	33,5	65,9
	Disagree	218	29,9	29,9	95,9
	Totally Disagree	23	3,2	3,2	99,0
	Not Applicable	7	1,0	1,0	100,0
	Total	728	100,0	100,0	

"I Adjust my Route to Avoid Parallel Parked Cars"

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Totally Agree	57	7,8	7,8	7,8
	Agree	151	20,7	20,7	28,6
	Disagree	318	43,7	43,7	72,3
	Totally Disagree	177	24,3	24,3	96,6
	Not Applicable	25	3,4	3,4	100,0
	Total	728	100,0	100,0	

“I Avoid ‘Unsafe’ Routes”

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Totally Agree	91	12,5	12,5	12,5
	Agree	265	36,4	36,4	48,9
	Disagree	244	33,5	33,5	82,4
	Totally Disagree	102	14,0	14,0	96,4
	Not Applicable	26	3,6	3,6	100,0
	Total	728	100,0	100,0	

“I Adjust my Route When Cycling with Children”

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Totally Agree	112	15,4	15,4	15,4
	Agree	216	29,7	29,7	45,1
	Disagree	67	9,2	9,2	54,3
	Totally Disagree	22	3,0	3,0	57,3
	Not Applicable	311	42,7	42,7	100,0
	Total	728	100,0	100,0	

“I Adjust my Route for a Better Scenery”

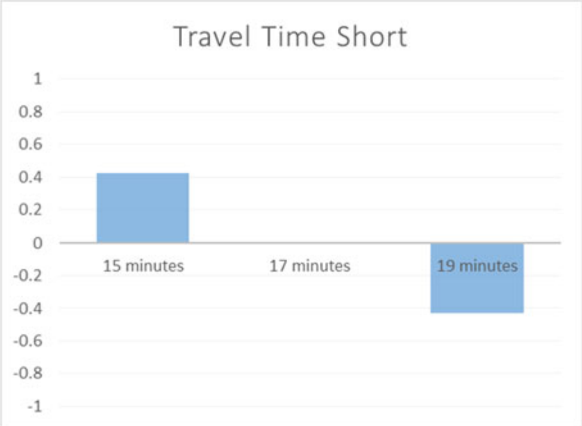
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Totally Agree	132	18,1	18,1	18,1
	Agree	355	48,8	48,8	66,9
	Disagree	157	21,6	21,6	88,5
	Totally Disagree	44	6,0	6,0	94,5
	Not Applicable	40	5,5	5,5	100,0
	Total	728	100,0	100,0	

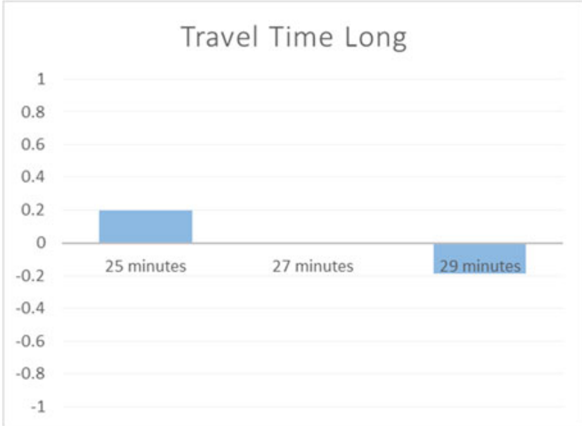
Appendix G: MNL Route-Choice Model Main Effects: NLogit Output

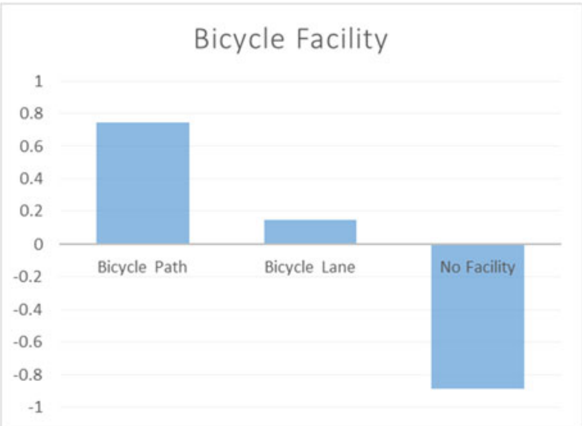
```
|-> SAMPLE ; All$
|-> reject; comptime<6$
|-> DISCRETECHOICE; lhs = choice
    ;choices = 1,2
    ;rhs                                                                =
prio1,prio2,facilit1,facilit2,nprio1,nprio2,trfl1,trfl2,pavq1,pavq2,travt_s
1,travt_s2,travt_l1,travt_l2,speed1,speed2,slope1,slope2$
Normal exit:   6 iterations. Status=0, F=    3390.489

---------------------------------------------------------------------------
Discrete choice (multinomial logit) model
Dependent variable               Choice
Log likelihood function     -3390.48946
Estimation based on N =   6552, K =  18
Inf.Cr.AIC  =   6817.0 AIC/N =    1.040
Model estimated: Dec 18, 2015, 08:58:00
R2=1-LogL/LogL* Log-L fncn R-sqrd R2Adj
Constants only  -4541.3782  .2534 .2514
Response data are given as ind. choices
Number of obs.=  6552, skipped   0 obs
--------+------------------------------------------------------------------
        |               Standard            Prob.      95% Confidence
  CHOICE|  Coefficient    Error       z    |z|>Z*         Interval
--------+------------------------------------------------------------------
   PRIO1|    .03748      .03057     1.23  .2202     -.02244    .09741
   PRIO2|   -.00925      .02919     -.32  .7514     -.06646    .04796
FACILIT1|    .74189***   .03295    22.52  .0000      .67731    .80646
FACILIT2|   -.88621***   .03191   -27.77  .0000     -.94875   -.82366
  NPRIO1|   -.27631***   .03012    -9.17  .0000     -.33535   -.21726
  NPRIO2|   -.07394**    .02963    -2.50  .0126     -.13202   -.01586
   TRFL1|   -.22063***   .03063    -7.20  .0000     -.28066   -.16060
   TRFL2|    .06868**    .02854     2.41  .0161      .01275    .12462
   PAVQ1|    .09789***   .02871     3.41  .0007      .04162    .15417
   PAVQ2|   -.72835***   .03082   -23.63  .0000     -.78875   -.66795
TRAVT_S1|    .42402***   .04545     9.33  .0000      .33494    .51310
TRAVT_S2|   -.43144***   .04366    -9.88  .0000     -.51702   -.34586
TRAVT_L1|    .19605***   .03850     5.09  .0000      .12060    .27150
TRAVT_L2|   -.18814***   .03831    -4.91  .0000     -.26324   -.11305
  SPEED1|   -.09235***   .02904    -3.18  .0015     -.14927   -.03543
  SPEED2|   -.20136***   .03030    -6.64  .0000     -.26075   -.14197
  SLOPE1|    .47309***   .03080    15.36  .0000      .41273    .53345
  SLOPE2|    .02821      .03136      .90  .3684     -.03326    .08968
--------+------------------------------------------------------------------
Note: ***, **, * ==>  Significance at 1%, 5%, 10% level.
---------------------------------------------------------------------------
```

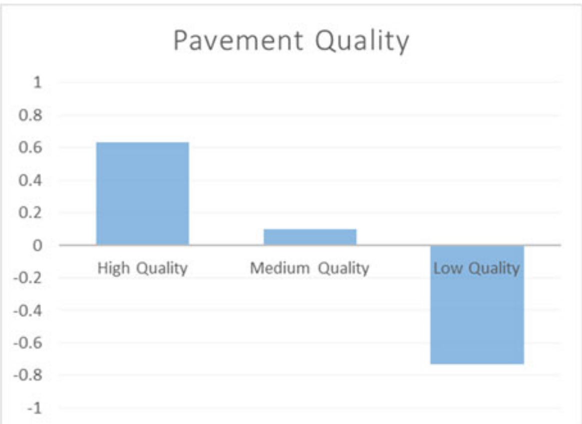
This page intentionally left blank.

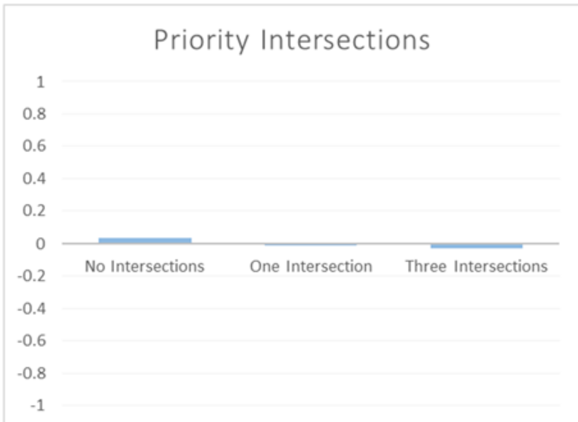
Appendix H: Route-Choice Utilities

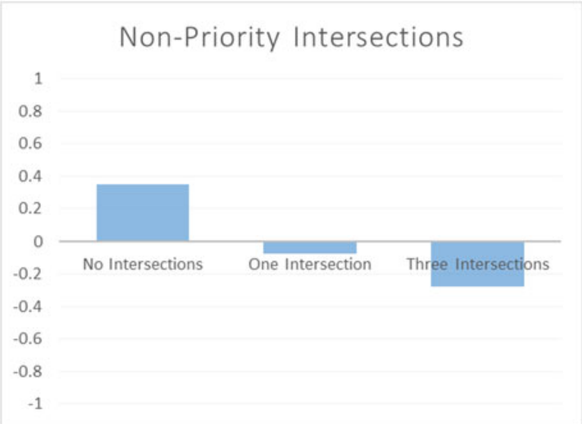


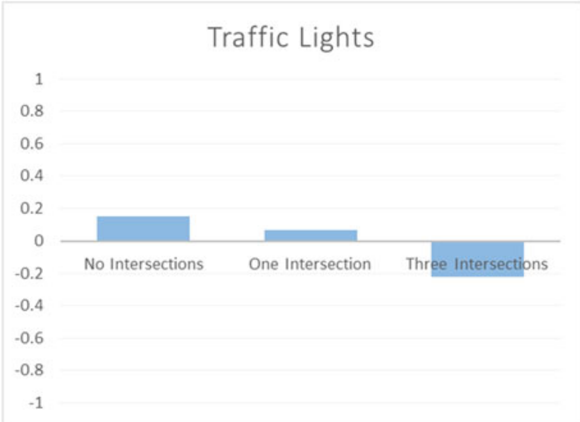


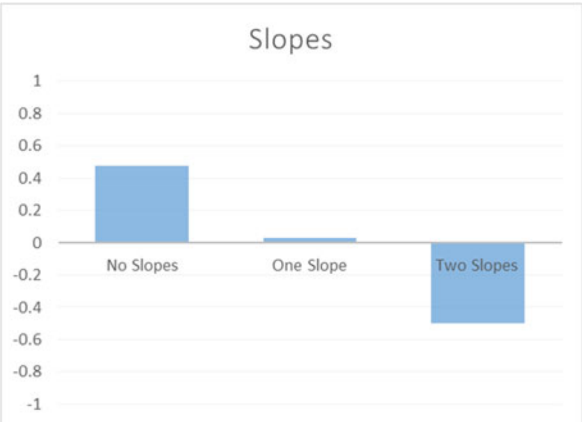







Non-Priority Intersections
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
No Intersections
One Intersection
Three Intersections


Traffic Lights
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
No Intersections
One Intersection
Three Intersections


Slopes
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
No Slopes
One Slope
Two Slopes

Appendix I: MNL Route-Choice Model Interaction Effects: NLogit Output

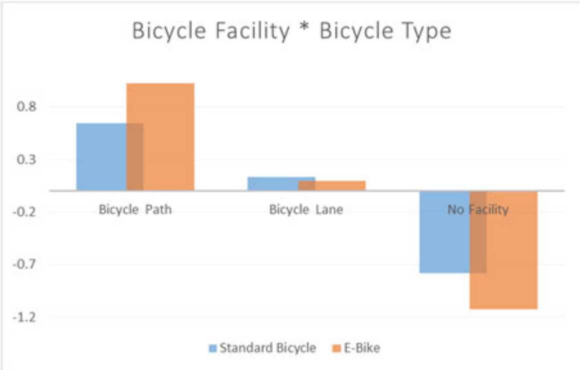
Code	*B*	*D*	*C*	*A*	*S*
1	Bicycle	Short	Commuting	18-35 years	Male
-1	E-Bike	Long	Recreation	36+ years	Female

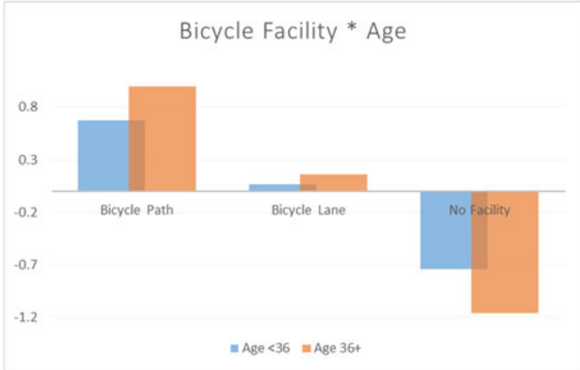
```
|-> SAMPLE ; All$
|-> reject; comptime<6$
|-> DISCRETECHOICE; lhs = choice
    ;choices = 1,2
    ;rhs                                                        =
prio1,prio2,facilit1,facilit2,nprio1,nprio2,trfl1,trfl2,pavq1,pavq2,travt_s
1,travt_s2,travt_l1,travt_l2,speed1,speed2,slope1,slope2,

B_fac1,B_fac2,B_nprio1,B_nprio2,A_fac1,A_fac2,A_trfl1,A_trfl2,S_slope1,S_sl
ope2,
    D_trfl1,D_trfl2,D_pavq1,D_pavq2,C_trfl1,C_trfl2,C_tt_l1,C_tt_l2,$
Normal exit:   6 iterations. Status=0, F=    3304.165

-----------------------------------------------------------------------------
Discrete choice (multinomial logit) model
Dependent variable                 Choice
Log likelihood function      -3304.16548
Estimation based on N =    6552, K =  36
Inf.Cr.AIC  =   6680.3 AIC/N =    1.020
Model estimated: Jan 11, 2016, 09:20:52
R2=1-LogL/LogL* Log-L fncn R-sqrd R2Adj
Constants only  -4541.3782  .2724 .2684
Response data are given as ind. choices
Number of obs.=  6552, skipped    0 obs
--------+--------------------------------------------------------------------
        |                Standard            Prob.      95% Confidence
  CHOICE|  Coefficient     Error       z    |z|>Z*         Interval
--------+--------------------------------------------------------------------
   PRIO1|    .03875        .03102     1.25  .2116     -.02205     .09955
   PRIO2|   -.01425        .02968     -.48  .6312     -.07241     .04392
FACILIT1|    .83660***     .05410    15.46  .0000      .73057     .94263
FACILIT2|   -.95164***     .05406   -17.60  .0000    -1.05760    -.84568
  NPRIO1|   -.36546***     .04735    -7.72  .0000     -.45827    -.27264
  NPRIO2|   -.01588        .04507     -.35  .7246     -.10422     .07247
   TRFL1|   -.27349***     .03428    -7.98  .0000     -.34067    -.20631
   TRFL2|    .05861*       .03167     1.85  .0643     -.00348     .12069
   PAVQ1|    .09073***     .02931     3.10  .0020      .03328     .14817
   PAVQ2|   -.73145***     .03147   -23.24  .0000     -.79312    -.66977
TRAVT_S1|    .40875***     .04546     8.99  .0000      .31965     .49785
TRAVT_S2|   -.43228***     .04382    -9.87  .0000     -.51816    -.34640
TRAVT_L1|    .18553***     .04095     4.53  .0000      .10528     .26579
TRAVT_L2|   -.13558***     .04085    -3.32  .0009     -.21565    -.05552
  SPEED1|   -.09527***     .02950    -3.23  .0012     -.15309    -.03746
  SPEED2|   -.19599***     .03082    -6.36  .0000     -.25640    -.13558
  SLOPE1|    .48340***     .03133    15.43  .0000      .42199     .54481
  SLOPE2|    .03661        .03192     1.15  .2513     -.02594     .09917
--------+--------------------------------------------------------------------
  B_FAC1|   -.19005***     .04969    -3.82  .0001     -.28743    -.09266
  B_FAC2|    .17138***     .05025     3.41  .0006      .07289     .26986
B_NPRIO1|    .10907**      .04653     2.34  .0191      .01786     .20027
B_NPRIO2|   -.07795*       .04461    -1.75  .0805     -.16538     .00948
  A_FAC1|   -.16369***     .03434    -4.77  .0000     -.23100    -.09637
  A_FAC2|    .21183***     .03335     6.35  .0000      .14647     .27720
 A_TRFL1|   -.09994***     .03449    -2.90  .0038     -.16755    -.03234
 A_TRFL2|   -.03072        .03239     -.95  .3429     -.09421     .03276
S_SLOPE1|   -.10029***     .02992    -3.35  .0008     -.15894    -.04164
S_SLOPE2|   -.01049        .03090     -.34  .7341     -.07105     .05006
```

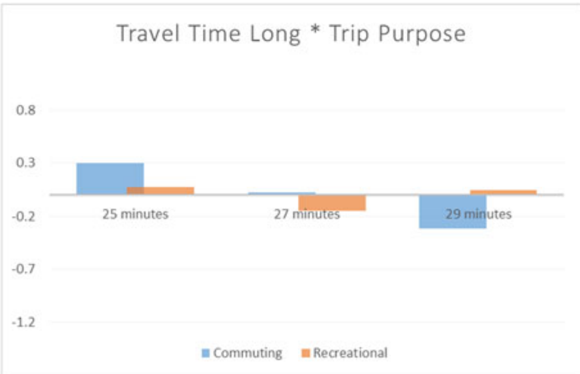
D_TRFL1	-.06948**	.03145	-2.21	.0271	-.13112	-.00785
D_TRFL2	.04846	.02985	1.62	.1045	-.01005	.10697
D_PAVQ1	-.03299	.02891	-1.14	.2538	-.08966	.02367
D_PAVQ2	.09967***	.03015	3.31	.0009	.04058	.15876
C_TRFL1	-.06933**	.03240	-2.14	.0324	-.13283	-.00583
C_TRFL2	.08613***	.03089	2.79	.0053	.02559	.14667
C_TT_L1	.11137***	.03970	2.81	.0050	.03357	.18918
C_TT_L2	-.17855***	.03999	-4.46	.0000	-.25693	-.10017

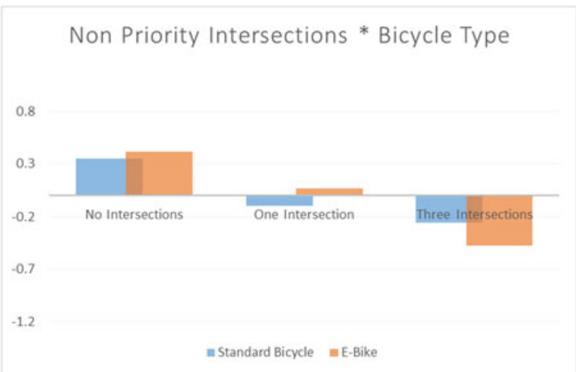
Note: ***, **, * ==> Significance at 1%, 5%, 10% level.

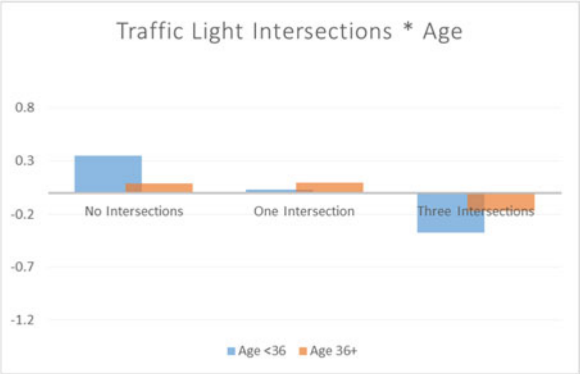
Appendix J: Route-choice Interaction Effects

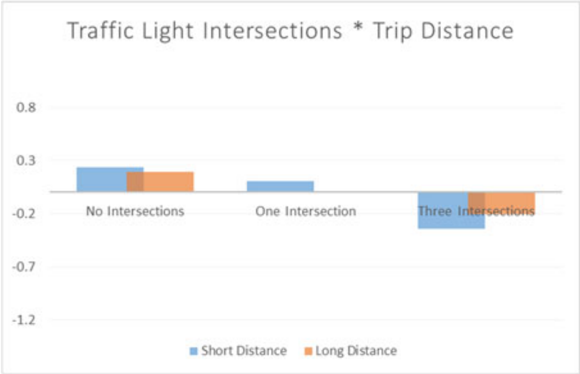


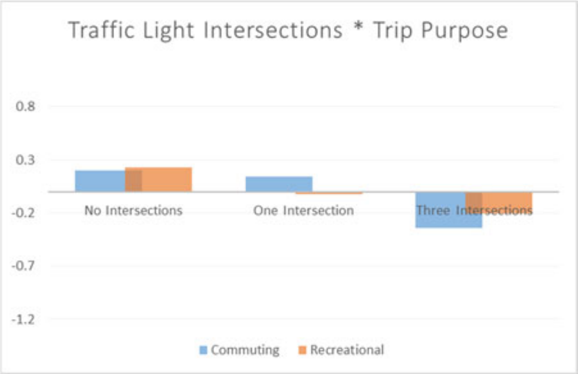







Traffic Light Intersections * Age
0.8
0.3
-0.2
-0.7
-1.2
No Intersections
One Intersection
Three Intersections
Age <36
Age 36+


Traffic Light Intersections * Trip Distance
0.8
0.3
-0.2
-0.7
-1.2
No Intersections
One Intersection
Three Intersections
Short Distance
Long Distance


Traffic Light Intersections * Trip Purpose
0.8
0.3
-0.2
-0.7
-1.2
No Intersections
One Intersection
Three Intersections
Commuting
Recreational

Appendix K: Ordinal Regression Route-Comfort: SPSS Output

Case Processing Summary

		N	Marginal Percentage
comfort	*	1534	11,7%
	**	4017	30,7%
	***	4668	35,6%
	****	2264	17,3%
	*****	621	4,7%
Priority_Intersections	No Intersections	4362	33,3%
	One Intersection	4375	33,4%
	Three Intersections	4367	33,3%
Facility_Type	Bicycle Path	4370	33,3%
	No Facility	4376	33,4%
	Bicycle Lane	4358	33,3%
Non_Priority_Intersections	Three Intersections	4369	33,3%
	One Intersection	4353	33,2%
	No Intersections	4382	33,4%
Traffic_Light_Intersections	Three Intersections	4375	33,4%
	One Intersection	4357	33,2%
	No Intersections	4372	33,4%
Pavement_Quality	Medium Quality	4376	33,4%
	Low Quality	4352	33,2%
	High Quality	4376	33,4%
Traffic_Speed	50 kmh	4360	33,3%
	60 kmh	4360	33,3%
	30 kmh	4384	33,5%
Slope	No Slope	4377	33,4%
	One Slope	4367	33,3%
	Two Slopes	4360	33,3%
Valid		13104	100,0%
Missing		0	
Total		13104	

Model Fitting Information

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	4245,035			
Final	753,830	3491,205	14	,000

Link function: Logit.

Goodness-of-Fit

	Chi-Square	df	Sig.
Pearson	171,486	90	,000
Deviance	170,402	90	,000

Link function: Logit.

Pseudo R-Square

Cox and Snell	,234
Nagelkerke	,248
McFadden	,093

Link function: Logit.

Parameter Estimates

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Threshold	[comfort *]	-3,553	,070	2593,531	1	,000	-3,690	-3,417
	[comfort **]	-1,597	,065	602,524	1	,000	-1,724	-1,469
	[comfort ***]	,311	,063	24,113	1	,000	,187	,435
	[comfort ****]	2,312	,071	1071,420	1	,000	2,174	2,451
Location	[No_Priority_Intersections]	,061	,039	2,426	1	,119	-,016	,139
	[One_Priority_Intersection]	,126	,039	10,209	1	,001	,049	,203
	[Three_Priority_Intersections]	0[a]	.	.	0	.	.	.
	[Facility = Bicycle Path]	,576	,040	210,849	1	,000	,499	,654
	[Facility = No Facility]	-,870	,040	471,434	1	,000	-,948	-,791
	[Facility = Bicycle Lane]	0[a]	.	.	0	.	.	.
	[Three_Non_Priority_Intersections]	-,332	,039	71,088	1	,000	-,410	-,255
	[One_Non_Priority_Intersection]	-,165	,039	17,643	1	,000	-,243	-,088
	[No_Non_Priority_Intersections]	0[a]	.	.	0	.	.	.
	[Three_Traffic_Light_Intersections]	-,231	,040	34,302	1	,000	-,309	-,154
	[One_Traffic_Light_Intersections]	-,210	,040	28,064	1	,000	-,288	-,132
	[No_Traffic_Light_Intersections]	0[a]	.	.	0	.	.	.
	[Pavement_Quality = Medium]	-,885	,040	488,171	1	,000	-,963	-,806
	[Pavement_Quality = Low]	-1,845	,042	1913,328	1	,000	-1,928	-1,763
	[Pavement_Quality = High]	0[a]	.	.	0	.	.	.
	[Traffic_Speed = 50 km/h]	-,405	,040	103,268	1	,000	-,483	-,327
	[Traffic_Speed = 60 km/h]	-,447	,040	126,332	1	,000	-,525	-,369
	[Traffic_Speed = 30 km/h]	0[a]	.	.	0	.	.	.
	[No_Slopes]	,647	,040	265,152	1	,000	,569	,724
	[One_Slope]	,408	,040	106,667	1	,000	,331	,486
	[Two_Slopes]	0[a]	.	.	0	.	.	.

Link function: Logit.
a. This parameter is set to zero because it is redundant.

Appendix L: Multinomial Logistic Regression Route-Comfort: SPSS Output

Case Processing Summary

		N	Marginal Percentage
comfort	*	1534	11,7%
	**	4017	30,7%
	***	4668	35,6%
	****	2264	17,3%
	*****	621	4,7%
Facility_Type	Bicycle Path	4370	33,3%
	No Facility	4376	33,4%
	Bicycle Lane	4358	33,3%
Non_Priority_Intersections	Three Intersections	4369	33,3%
	One Intersection	4353	33,2%
	No Intersections	4382	33,4%
Traffic_Light_Intersections	Three Intersections	4375	33,4%
	One Intersection	4357	33,2%
	No Intersections	4372	33,4%
Pavement_Quality	Medium Quality	4376	33,4%
	Low Quality	4352	33,2%
	High Quality	4376	33,4%
Traffic_Speed	50 kmh	4360	33,3%
	60 kmh	4360	33,3%
	30 kmh	4384	33,5%
Slope	No Slope	4377	33,4%
	One Slope	4367	33,3%
	Two Slopes	4360	33,3%
disclass	Long	7326	55,9%
	Short	5778	44,1%
Age	36+	9288	70,9%
	till 35	3816	29,1%
Commute	Recreational	6264	47,8%
	Commuting	6840	52,2%
Valid		13104	100,0%
Missing		0	
Total		13104	
Subpopulation		216[a]	

a. The dependent variable has only one value observed in 1 (,5%) subpopulations.

Model Fitting Information

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	7143,143			
Final	3341,046	3802,097	108	,000

Goodness-of-Fit

	Chi-Square	df	Sig.
Pearson	732,812	752	,685
Deviance	793,942	752	,140

Pseudo R-Square

Cox and Snell	,252
Nagelkerke	,267
McFadden	,102

Likelihood Ratio Tests

Effect	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept	3341,046[a]	,000	0	.
Facility_Type	3341,046[a]	,000	0	.
Non_Priority_Intersections	3413,344	72,298	8	,000
Traffic_Light_Intersections	3341,046[a]	,000	0	.
Pavement_Quality	4980,294	1639,248	8	,000
Traffic_Speed	3341,046[a]	,000	0	.
Slope	3341,046[a]	,000	0	.
Facility_Type * disclass	3359,241	18,195	8	,020
Traffic_Light_Intersections * disclass	3361,113	20,067	8	,010
Facility_Type * Age	3377,523	36,477	8	,000
Slope * Age	3357,245	16,198	8	,040
Traffic_Speed * Commute	3364,760	23,714	12	,022
Traffic_Speed * disclass	3354,939	13,893	8	,085

Parameter Estimates
(Interaction effects are left out of this table)

comfort[a]		B	Std. Error	Wald	df	Sig.	Exp(B)	95% Confidence Interval for Exp(B) Lower Bound	Upper Bound
*	Intercept	-2,554	,242	111,482	1	,000			
	[Facility_Type=0]	,081	,214	,142	1	,706	1,084	,713	1,648
	[Facility_Type=1]	,972	,182	28,436	1	,000	2,643	1,849	3,777
	[Facility_Type=2]	0[b]	.	.	0	.	.	.	.
	[Non_Priority_Intersections=0]	,239	,077	9,747	1	,002	1,270	1,093	1,475
	[Non_Priority_Intersections=1]	,114	,077	2,193	1	,139	1,121	,964	1,304
	[Non_Priority_Intersections=2]	0[b]	.	.	0	.	.	.	.
	[Traffic_Light_Intersections=0]	-,262	,142	3,429	1	,064	,769	,583	1,015
	[Traffic_Light_Intersections=1]	-,227	,129	3,111	1	,078	,797	,619	1,026
	[Traffic_Light_Intersections=2]	0[b]	.	.	0	.	.	.	.
	[Pavement_Quality=0]	,393	,104	14,172	1	,000	1,482	1,207	1,819
	[Pavement_Quality=1]	1,736	,094	338,505	1	,000	5,675	4,717	6,828
	[Pavement_Quality=2]	0[b]	.	.	0	.	.	.	.
	[Traffic_Speed=0]	-,143	,174	,677	1	,411	,867	,616	1,219
	[Traffic_Speed=1]	,019	,173	,011	1	,915	1,019	,725	1,431
	[Traffic_Speed=2]	0[b]	.	.	0	.	.	.	.
	[Slope=0]	-,382	,152	6,336	1	,012	,682	,507	,919
	[Slope=1]	-,347	,152	5,218	1	,022	,706	,524	,952
	[Slope=2]	0[b]	.	.	0	.	.	.	.
**	Intercept	-,813	,144	31,795	1	,000			
	[Facility_Type=0]	-,290	,119	5,952	1	,015	,748	,593	,945
	[Facility_Type=1]	,188	,110	2,909	1	,088	1,207	,972	1,499
	[Facility_Type=2]	0[b]	.	.	0	.	.	.	.
	[Non_Priority_Intersections=0]	,215	,055	15,536	1	,000	1,240	1,114	1,381
	[Non_Priority_Intersections=1]	,191	,055	12,059	1	,001	1,210	1,087	1,348
	[Non_Priority_Intersections=2]	0[b]	.	.	0	.	.	.	.
	[Traffic_Light_Intersections=0]	,032	,086	,134	1	,715	1,032	,872	1,222
	[Traffic_Light_Intersections=1]	,111	,084	1,756	1	,185	1,117	,948	1,317
	[Traffic_Light_Intersections=2]	0[b]	.	.	0	.	.	.	.
	[Pavement_Quality=0]	,310	,059	27,452	1	,000	1,363	1,214	1,531
	[Pavement_Quality=1]	1,067	,059	322,825	1	,000	2,907	2,587	3,265
	[Pavement_Quality=2]	0[b]	.	.	0	.	.	.	.
	[Traffic_Speed=0]	,275	,110	6,247	1	,012	1,317	1,061	1,634
	[Traffic_Speed=1]	,354	,111	10,155	1	,001	1,424	1,146	1,770
	[Traffic_Speed=2]	0[b]	.	.	0	.	.	.	.
	[Slope=0]	-,497	,099	25,184	1	,000	,608	,501	,739
	[Slope=1]	-,333	,098	11,670	1	,001	,717	,592	,868
	[Slope=2]	0[b]	.	.	0	.	.	.	.
****	Intercept	-,598	,165	13,119	1	,000			
	[Facility_Type=0]	,493	,134	13,553	1	,000	1,638	1,259	2,130
	[Facility_Type=1]	-,581	,166	12,234	1	,000	,559	,404	,774
	[Facility_Type=2]	0[b]	.	.	0	.	.	.	.
	[Non_Priority_Intersections=0]	-,244	,065	14,291	1	,000	,783	,690	,889
	[Non_Priority_Intersections=1]	-,116	,065	3,182	1	,074	,891	,784	1,012
	[Non_Priority_Intersections=2]	0[b]	.	.	0	.	.	.	.
	[Traffic_Light_Intersections=0]	-,160	,126	1,618	1	,203	,852	,666	1,090
	[Traffic_Light_Intersections=1]	,130	,109	1,405	1	,236	1,138	,919	1,410
	[Traffic_Light_Intersections=2]	0[b]	.	.	0	.	.	.	.
	[Pavement_Quality=0]	-,794	,064	153,800	1	,000	,452	,399	,513
	[Pavement_Quality=1]	-1,181	,080	218,725	1	,000	,307	,262	,359
	[Pavement_Quality=2]	0[b]	.	.	0	.	.	.	.

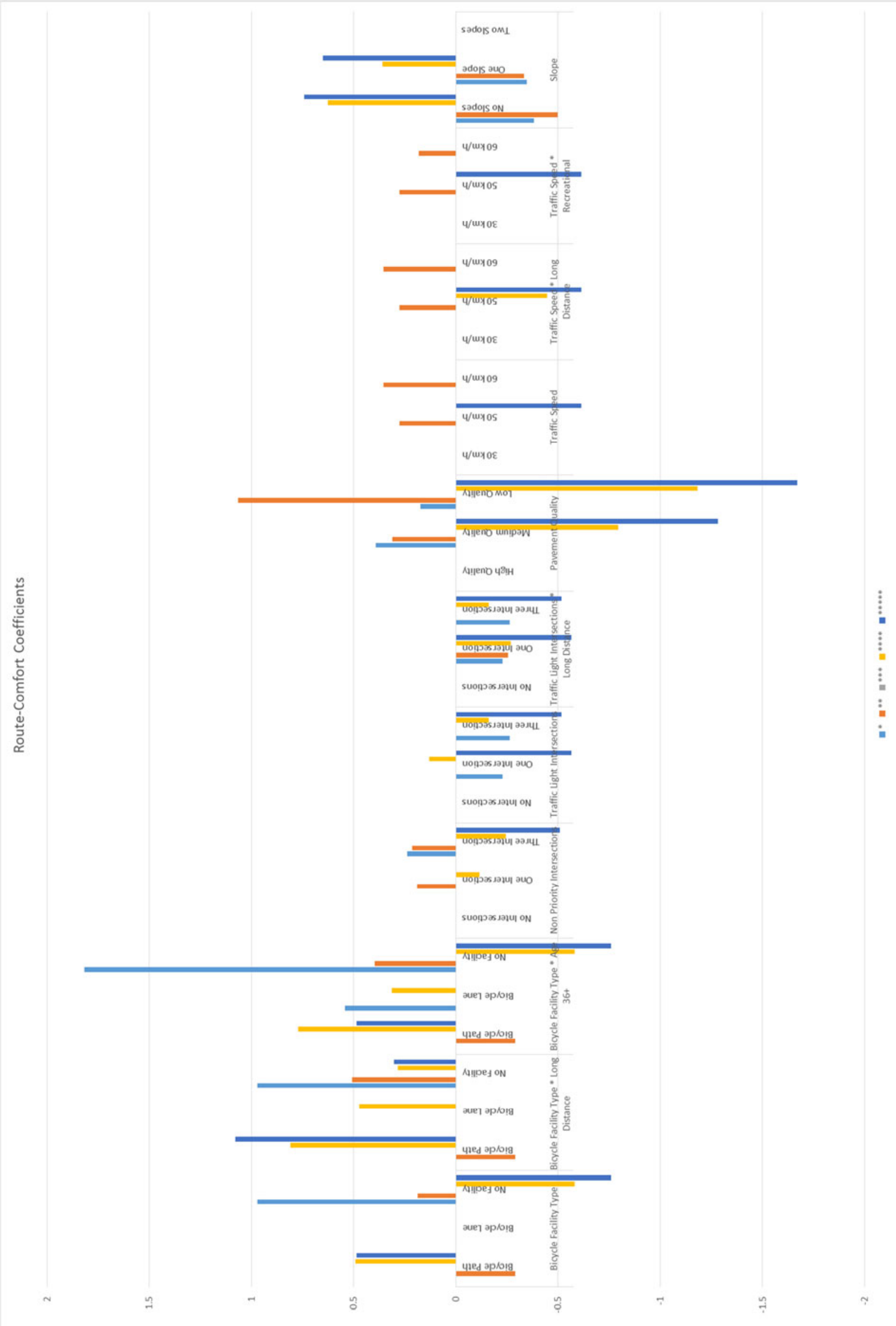
	[Traffic_Speed=0]	,005	,144	,001	1	,975	1,005	,757	1,333
	[Traffic_Speed=1]	-,081	,145	,309	1	,579	,922	,694	1,226
	[Traffic_Speed=2]	0[b]	.	.	0	.	.	.	.
	[Slope=0]	,626	,122	26,338	1	,000	1,870	1,473	2,376
	[Slope=1]	,360	,127	8,091	1	,004	1,433	1,118	1,837
	[Slope=2]	0[b]	.	.	0	.	.	.	.
*****	Intercept	-1,375	,328	17,554	1	,000			
	[Facility_Type=0]	,487	,275	3,141	1	,076	1,627	,950	2,787
	[Facility_Type=1]	-,760	,371	4,202	1	,040	,468	,226	,967
	[Facility_Type=2]	0[b]	.	.	0	.	.	.	.
	[Non_Priority_Intersections=0]	-,509	,125	16,678	1	,000	,601	,471	,767
	[Non_Priority_Intersections=1]	-,108	,114	,883	1	,347	,898	,718	1,124
	[Non_Priority_Intersections=2]	0[b]	.	.	0	.	.	.	.
	[Traffic_Light_Intersections=0]	-,517	,294	3,093	1	,079	,597	,335	1,061
	[Traffic_Light_Intersections=1]	-,565	,256	4,865	1	,027	,569	,344	,939
	[Traffic_Light_Intersections=2]	0[b]	.	.	0	.	.	.	.
	[Pavement_Quality=0]	-1,281	,127	101,990	1	,000	,278	,217	,356
	[Pavement_Quality=1]	-1,669	,165	102,022	1	,000	,188	,136	,261
	[Pavement_Quality=2]	0[b]	.	.	0	.	.	.	.
	[Traffic_Speed=0]	-,613	,316	3,771	1	,052	,542	,292	1,006
	[Traffic_Speed=1]	-,353	,312	1,282	1	,258	,702	,381	1,295
	[Traffic_Speed=2]	0[b]	.	.	0	.	.	.	.
	[Slope=0]	,743	,218	11,629	1	,001	2,102	1,372	3,222
	[Slope=1]	,651	,219	8,848	1	,003	1,917	1,249	2,945
	[Slope=2]	0[b]	.	.	0	.	.	.	.

a. The reference category is: ***.
b. This parameter is set to zero because it is redundant.

Effect	Level	*	**	***	****	*****
Bicycle Facility Type	Bicycle Path * Long Dist.	-0.113	0.197	0	0.316	0.593
** Distance Class*	Bicycle Path * Short Dist.	0	0	0	0	0
	Bicycle Lane * Long Dist.	-0.080	0.126	0	0.472	0.307
	Bicycle Lane * Short Dist.	0	0	0	0	0
	No Facility * Long Dis.	-0.108	0.320	0	0.864	1.063
	No Facility * Short Dist.	0	0	0	0	0
Traffic Light Intersections	No Intersections * Long Dist.	0	0	0	0	0
** Distance Class*	No Intersections * Short Dist.	0	0	0	0	0
	One Intersection * Long Dist.	-0.158	-0.254	0	-0.399	0.046
	One Intersection * Short Dist.	0	0	0	0	0
	Three Intersections * Long Dist.	-0.285	-0.143	0	0.023	0.082
	Three Intersections * Short Dist.	0	0	0	0	0
Traffic Speed	30 km/h * Long Dist.	0	0	0	0	0
** Distance Class*	30 km/h * Short Dist.	0	0	0	0	0
	50 km/h * Long Dist.	0.140	0.275	0	-0.447	-0.046
	50 km/h * Short Dist.	0	0	0	0	0
	60 km/h * Long Dist.	0.188	0.354	0	-0.191	-0.185
	60 km/h * Short Dist.	0	0	0	0	0
Bicycle Facility Type	Bicycle Path * Age 36+	0.248	-0.103	0	0.278	0.040
** Age*	Bicycle Path * Age <36	0	0	0	0	0
	Bicycle Lane * Age 36+	0.543	-0.070	0	0.314	-0.126
	Bicycle Lane * Age <36	0	0	0	0	0
	No Facility * Age 36+	0.846	0.208	0	-0.082	-0.504
	No Facility * Age <36	0	0	0	0	0
*Slope * Age*	No Slopes * Age 36+	-0.251	-0.183	0	-0.227	0.257
	No Slopes * Age <36	0	0	0	0	0
	One Slope * Age 36+	-0.193	0.138	0	-0.170	-0.157
	One Slope * Age <36	0	0	0	0	0
	Two Slopes * Age 36+	0	0	0	0	0
	Two Slopes * Age <36	0	0	0	0	0
Traffic Speed	30 km/h * Recreational	-0.005	-0.020	0	0.006	-0.067
** Trip Purpose*	30 km/h * Commuting	0	0	0	0	0
	50 km/h * Recreational	0.283	0.087	0	0.146	0.076
	50 km/h * Commuting	0	0	0	0	0
	60 km/h * Recreational	0.185	-0.172	0	-0.169	-0.326
	60 km/h * Commuting	0	0	0	0	0

Insignificant within the 90% confidence interval

Appendix M: Route-Comfort Coefficients with Interaction Effects



Appendix N: MNL Mode-Choice Model Main Effects: NLogit Output

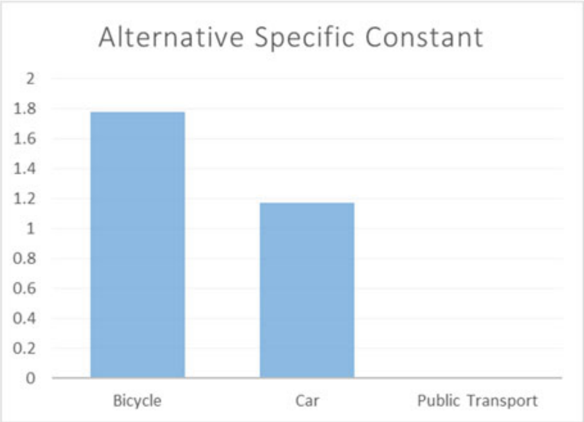
```
|-> SAMPLE ; All$
|-> reject; COMPTIME<6$
|-> DISCRETECHOICE; lhs = choice
    ;choices = Bike,Car,PT
    ;rhs =
ONE,BTT_S1,BTT_S2,BTT_L1,BTT_L2,B_PARK1,B_PARK2,COMFORT1,COMFORT2,CTT1,CTT2
,C_DEL1,C_DEL2,C_PARK1,C_PARK2,PTTT1,PTTT2,PT_DEL1,PT_DEL2$
Normal exit:   5 iterations. Status=0, F=    5673.345

-----------------------------------------------------------------------------
Discrete choice (multinomial logit) model
Dependent variable               Choice
Log likelihood function     -5673.34534
Estimation based on N =   6552, K =  20
Inf.Cr.AIC  =  11386.7 AIC/N =    1.738
Model estimated: Jan 02, 2016, 13:47:53
R2=1-LogL/LogL* Log-L fncn R-sqrd R2Adj
Constants only  -6033.2526  .0597 .0582
Chi-squared[18]          =    719.81461
Prob [ chi squared > value ] =   .00000
Response data are given as ind. choices
Number of obs.=  6552, skipped    0 obs
```

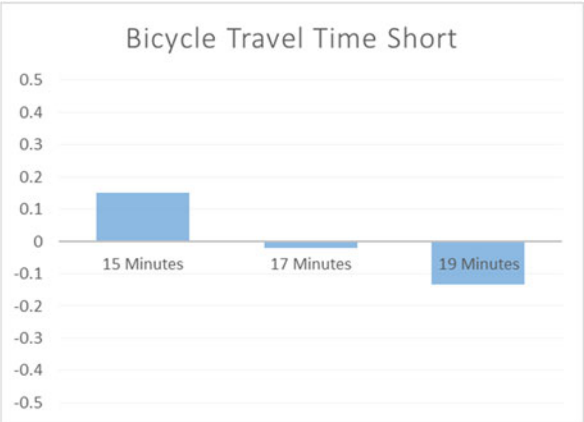
CHOICE	Coefficient	Standard Error	z	Prob. |z|>Z*	95% Confidence Interval	
BTT_S1	.15238***	.05513	2.76	.0057	.04432	.26043
BTT_S2	-.01944	.05566	-.35	.7269	-.12854	.08966
BTT_L1	-.00744	.04883	-.15	.8790	-.10315	.08827
BTT_L2	.05865	.04933	1.19	.2345	-.03804	.15534
B_PARK1	.41206***	.03823	10.78	.0000	.33713	.48698
B_PARK2	-.27765***	.03678	-7.55	.0000	-.34975	-.20556
COMFORT1	-.29888***	.03748	-7.97	.0000	-.37235	-.22542
COMFORT2	.05237	.03700	1.42	.1570	-.02016	.12489
CTT1	-.44222***	.04135	-10.69	.0000	-.52326	-.36117
CTT2	-.04724	.03912	-1.21	.2272	-.12391	.02943
C_DEL1	-.04737	.03998	-1.18	.2361	-.12574	.03099
C_DEL2	-.21890***	.04247	-5.15	.0000	-.30214	-.13566
C_PARK1	.37485***	.03808	9.84	.0000	.30022	.44948
C_PARK2	-.41761***	.04110	-10.16	.0000	-.49817	-.33705
PTTT1	.02044	.06225	.33	.7427	-.10158	.14245
PTTT2	-.38483***	.06419	-6.00	.0000	-.51064	-.25903
PT_DEL1	.32035***	.05666	5.65	.0000	.20929	.43141
PT_DEL2	-.09972	.06076	-1.64	.1008	-.21881	.01938
A_BIKE	1.77914***	.04478	39.73	.0000	1.69138	1.86691
A_CAR	1.16974***	.04751	24.62	.0000	1.07663	1.26285

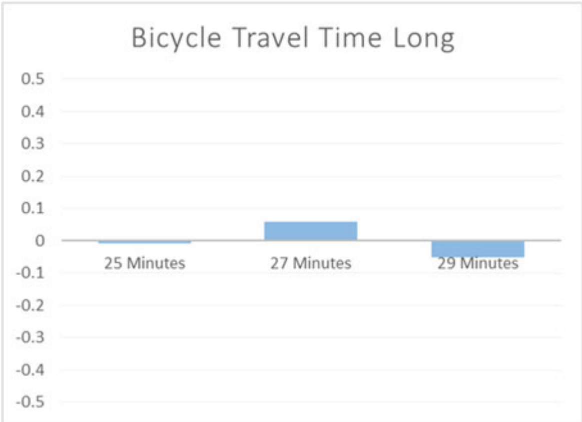
Note: ***, **, * ==> Significance at 1%, 5%, 10% level.

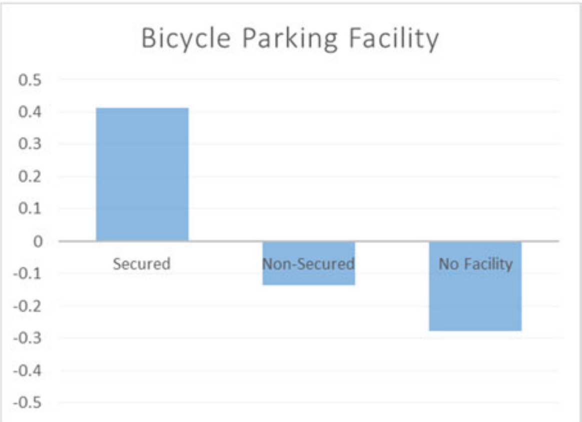
This page intentionally left blank.

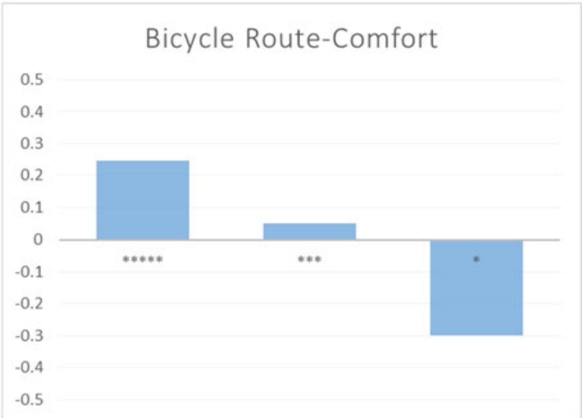
Appendix O: Mode-Choice Utilities

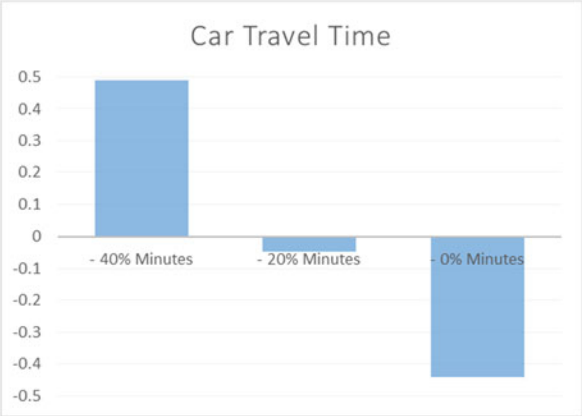


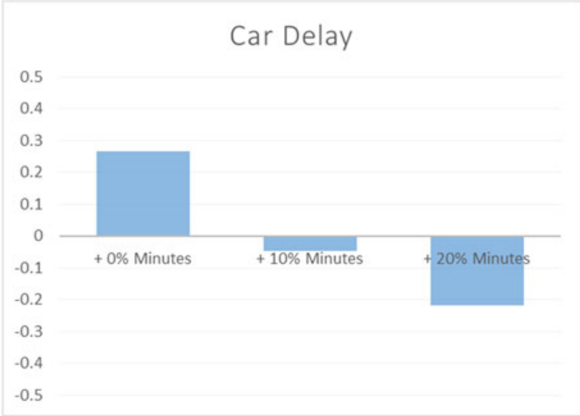


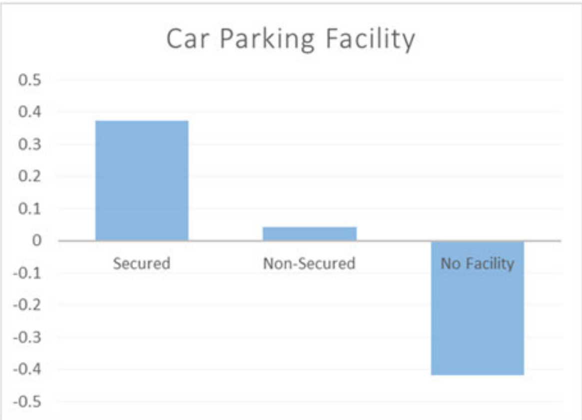


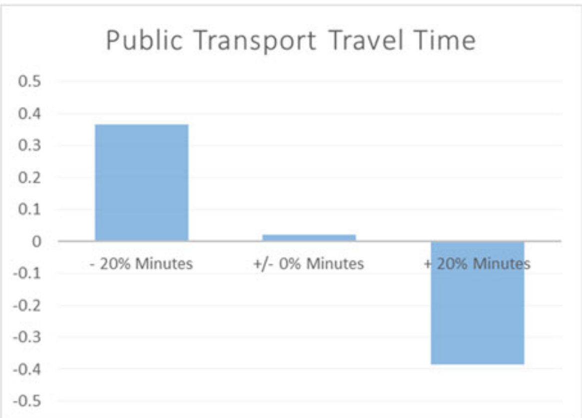


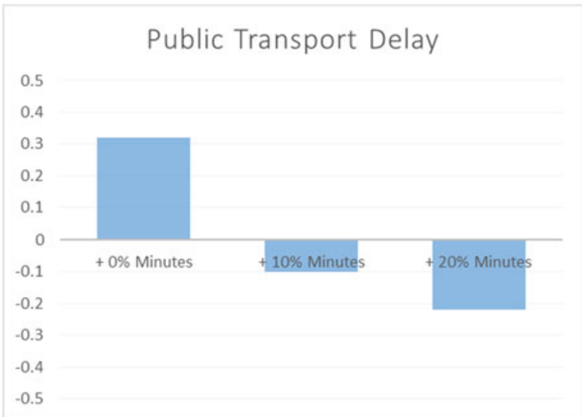



Car Travel Time
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
- 40% Minutes
- 20% Minutes
- 0% Minutes


Car Delay
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
+ 0% Minutes
+ 10% Minutes
+ 20% Minutes


Car Parking Facility
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
Secured
Non-Secured
No Facility


Public Transport Travel Time
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
- 20% Minutes
+/- 0% Minutes
+ 20% Minutes


Public Transport Delay
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
+ 0% Minutes
+ 10% Minutes
+ 20% Minutes

Appendix P:MNL Mode-Choice Model Interaction Effects: NLogit Output

Code	*B*	*D*	*C*	*A*	*S*
1	Bicycle	Short	Commuting	18-35 years	Male
-1	E-Bike	Long	Recreation	36+ years	Female

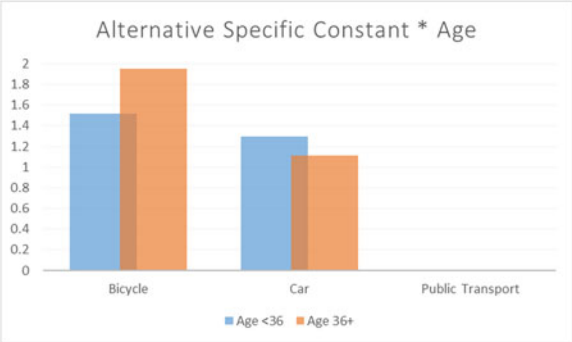
```
|-> SAMPLE ; All$
|-> DISCRETECHOICE; lhs = choice
    ;choices = Bike,Car,PT
    ;rhs =

ASC_B,ASC_C,BTT_S1,BTT_S2,BTT_L1,BTT_L2,B_PARK1,B_PARK2,COMFORT1,COMFORT2,C
TT1,CTT2,C_DEL1,C_DEL2,C_PARK1,C_PARK2,PTTT1,PTTT2,PT_DEL1,PT_DEL2,

B_ASCB,B_ASCC,A_ASCB,A_ASCC,S_ASCB,S_ASCC,D_ASCB,D_ASCC,C_ASCB,C_ASCC,D_BPA
RK1,D_BPARK2,C_BPARK1,C_BPARK2,C_CTT1,C_CTT2,D_CPARK1,D_CPARK2
    $
Normal exit:    6 iterations. Status=0, F=    5477.591
```

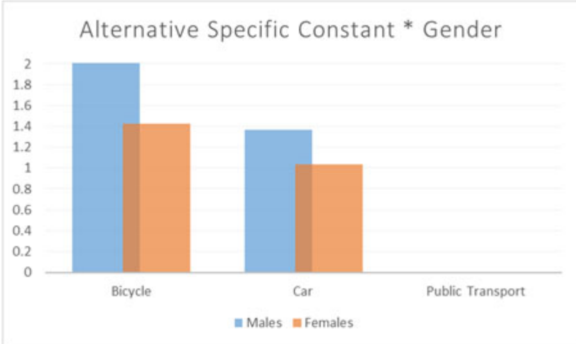
```
Discrete choice (multinomial logit) model
Dependent variable                 Choice
Log likelihood function       -5477.59143
Estimation based on N =    6552, K =   38
Inf.Cr.AIC  =  11031.2 AIC/N =    1.684
Model estimated: Feb 16, 2016, 09:06:30
R2=1-LogL/LogL* Log-L fncn R-sqrd R2Adj
Constants only  -6033.2526  .0921 .0895
Response data are given as ind. choices
Number of obs.=  6552, skipped    0 obs
--------+--------------------------------------------------------------------
        |                Standard            Prob.       95% Confidence
  CHOICE|  Coefficient     Error       z    |z|>Z*          Interval
--------+--------------------------------------------------------------------
   ASC_B|    1.73523***    .07249    23.94  .0000     1.59316   1.87730
   ASC_C|    1.20264***    .07684    15.65  .0000     1.05204   1.35324
  BTT_S1|     .18457***    .05547     3.33  .0009      .07585    .29329
  BTT_S2|    -.04316       .05646     -.76  .4446     -.15382    .06750
  BTT_L1|    -.00125       .05085     -.02  .9805     -.10090    .09841
  BTT_L2|     .05410       .05133     1.05  .2919     -.04650    .15471
 B_PARK1|     .42581***    .03961    10.75  .0000      .34817    .50345
 B_PARK2|    -.29627***    .03809    -7.78  .0000     -.37092   -.22163
COMFORT1|    -.30987***    .03851    -8.05  .0000     -.38535   -.23440
COMFORT2|     .05825       .03799     1.53  .1252     -.01620    .13270
    CTT1|    -.47254***    .04288   -11.02  .0000     -.55658   -.38851
    CTT2|    -.04958       .04018    -1.23  .2172     -.12834    .02918
  C_DEL1|    -.05559       .04099    -1.36  .1751     -.13593    .02476
  C_DEL2|    -.23026***    .04360    -5.28  .0000     -.31571   -.14480
 C_PARK1|     .38189***    .03914     9.76  .0000      .30517    .45860
 C_PARK2|    -.43309***    .04201   -10.31  .0000     -.51543   -.35076
   PTTT1|     .02758       .06293      .44  .6612     -.09576    .15091
   PTTT2|    -.40154***    .06477    -6.20  .0000     -.52848   -.27460
 PT_DEL1|     .33715***    .05702     5.91  .0000      .22538    .44891
 PT_DEL2|    -.11228*      .06109    -1.84  .0661     -.23202    .00745
--------+--------------------------------------------------------------------

  B_ASCB|    -.06282       .06583     -.95  .3399     -.19183    .06620
  B_ASCC|     .01364       .07067      .19  .8470     -.12487    .15214
  A_ASCB|    -.21694***    .04949    -4.38  .0000     -.31393   -.11994
  A_ASCC|     .09341*      .05181     1.80  .0714     -.00814    .19496
  S_ASCB|     .30724***    .04427     6.94  .0000      .22047    .39400
  S_ASCC|     .16672***    .04687     3.56  .0004      .07484    .25859
  D_ASCB|    -.08998**     .04590    -1.96  .0499     -.17993   -.00002
```

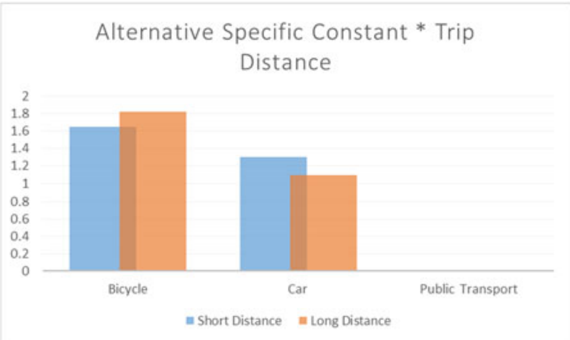
D_ASCC	.10429**	.04828	2.16	.0308	.00966	.19892
C_ASCB	.17353***	.04641	3.74	.0002	.08256	.26450
C_ASCC	-.21325***	.04920	-4.33	.0000	-.30968	-.11682
D_BPARK1	-.08076**	.03975	-2.03	.0422	-.15867	-.00285
D_BPARK2	-.00948	.03845	-.25	.8053	-.08484	.06588
C_BPARK1	.07490*	.03977	1.88	.0596	-.00304	.15284
C_BPARK2	-.06390*	.03820	-1.67	.0944	-.13877	.01097
C_CTT1	-.09059**	.04233	-2.14	.0324	-.17356	-.00762
C_CTT2	.04234	.04010	1.06	.2910	-.03625	.12093
D_CPARK1	.00963	.03890	.25	.8046	-.06662	.08587
D_CPARK2	-.09033**	.04136	-2.18	.0290	-.17139	-.00926

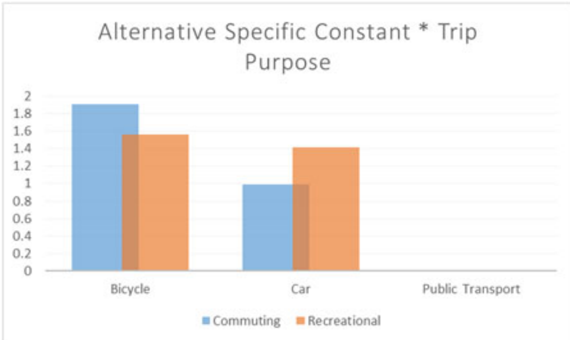
Note: ***, **, * ==> Significance at 1%, 5%, 10% level.

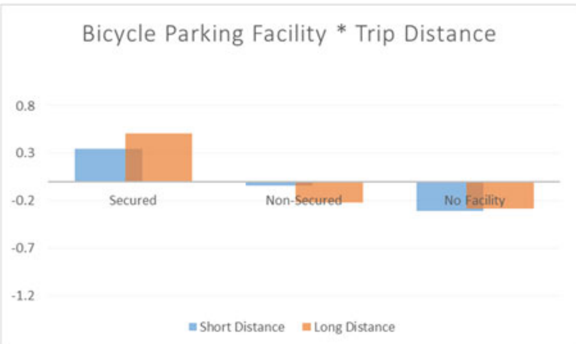
Appendix Q: Mode-Choice Interaction Effects

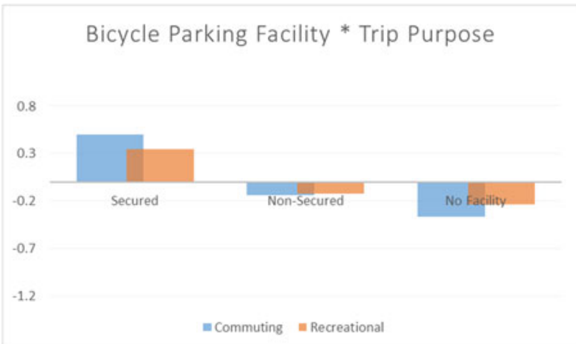


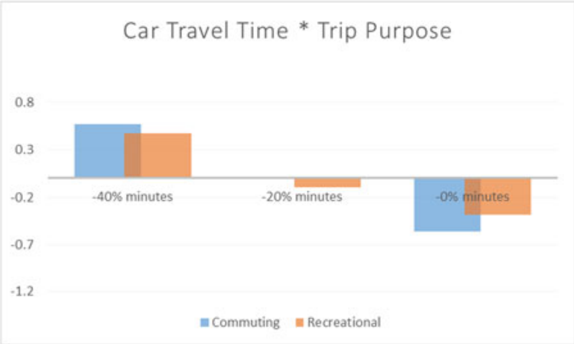











Car Travel Time * Trip Purpose
0.8
0.3
-0.2
-0.7
-1.2
-40% minutes
-20% minutes
-0% minutes
Commuting
Recreational


Car Parking Facility * Trip Distance
0.8
0.3
-0.2
-0.7
-1.2
Secured
Non-Secured
No Facility
Short Distance
Long Distance