Evaluation of trip characteristics and accessibility in car-free development

A case study in the Merwedekanaalzone in Utrecht

August 2020 – February 2021

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Abbreviations

Abbreviation	Meaning
AIC	Akaike Information Criterion
ASC	Alternative-specific constant
BIC	Bayesian Information Criterion
BTM	Bus, tram, metro
CBS	Statistics Netherlands (Dutch: Centraal Bureau voor de Statistiek)
CFD	Car-free developmend
GIS	Geographic Information System
IIA	Independence of Irrelevant Alternatives
KiM	Netherlands Institute for Transport Policy Analysis (Dutch: Kennisinstituut voor Mobilteitsbeleid)
LCL	Latent Class Logit
LISA	National database for job opportunities (Dutch: Landelijk Informatiesysteem van Arbeidsplaatsen)
MNL	Multinomial Logit
MM	Mott MacDonald
MPN	Mobility Panel Netherlands (Dutch: Mobiliteitspanel Nederland)
OSM	OpenStreetMap
PAR	Provincial database for job opportunities in Utrecht (Dutch: Provinciaal Arbeidsplaatsen Register)
PC4	Postal Code with four digits, resulting in larger areas
PC6	Postal Code with four digits and two letters, resulting in smaller areas
TAZ	Traffic Analysis Zone

Abstract

Utrecht is one of the fastest growing cities in the Netherlands, with a 30% expected increase in residents in 2040. To facilitate this increase in inhabitants, the municipality has designated areas in the inner parts of the city to be redeveloped as car-free, with the Merwedekanaalzone being the largest area with over 8000 residences. Not only does this contribute to the level of healthy urban living that the municipality strives for, it also aims to relieve the already stressed car transport system around the area. As there are no car-free areas that have been developed on a scale like this, it is unsure which type of persons will relocate towards the area and how accessibility is assured using alternative transport modes.

This research focusses on determining socio-economic and transport characteristics of potential residents in car-free development, as well as on developing an accessibility model that can evaluate job accessibility with respect to the preferences of different population groups in the Merwedekanaalzone. To do so, a survey is distributed in car-free residential areas in Utrecht (48 responses), Amsterdam (87 responses) and Groningen (69 responses). A revealed preference part within this survey determines socio-economic and travel characteristics of the respondents, while a stated preference part evaluates trip characteristics in public transport. The relative importance of those trip characteristics, being costs, in-vehicle time, access walking time and waiting time, are used in a location-based accessibility model to evaluate job accessibility in the Merwedekanaalzone in the current situation as well as future scenarios.

Results that have been compared with the Mobility Panel Netherlands survey, a nationwide transport survey, show that (self-)employed persons and high-income households are present more often in car-free development, while children are less often present. As expected, car ownership is low in these areas, with half of the respondents not owning a car and the other half mostly owning only a single car. Reasons to own a car are an increased level of mobility and accessibility, as well as a sense of control or freedom that it provides. As respondents state that job commuting is mostly done by bike, this indicates that residential self-selection is possible present within the areas. Surprisingly, shared cars are only used marginally, while most respondents state that shared cars are available in their neighbourhood. This is strengthened by the negative attitude that respondents have towards especially a shared car that is also used by strangers.

To account for socio-economic characteristics while alternatives are not inherently different in the choice experiment, latent class logit regression is used to evaluate trip characteristics for different population groups. A regression model with three latent classes best describes the collected data, with probabilities to perceive a commuting trip as acceptable especially decreasing with an increased travel distance (Class 1), an increased out-of-vehicle travel time (Class 2) and travelling in general (Class 3). Differences in age, income, car ownership and household size determine the probability to belong to a certain class.

By using the developed accessibility model in the Merwedekanaalzone, it is found that in the current situation senior adults and high-income households perceive the least number of job opportunities to be available, while families and low-income households perceive the most jobs to be accessibility. In case of a bike-and-ride scenario, job accessibility increases to almost twice the amount for all population groups compared to a walk-and-ride scenario. Developing the internal street network in the area without implementing other measures improves accessibility significantly, due to the current impenetrable appearance. Realising bridges across the Merwedekanaal results in the largest increase in job accessibility, due to the canal currently acting as a natural barrier. No notable differences between the two tram routes can be distinguished, which is however dependent on the origin location in the model. Upgrading train station Lunetten to serve intercity trains does not increase accessibility. In comparison to other areas in Utrecht that are possibly developed as being car-free, the Merwedekanaalzone provides average numbers of job accessibility, with the transport network being more important than the proximity of job opportunities when determining job accessibility.

Samenvatting

Utrecht is één van de snelstgroeiende steden van Nederland, met in 2040 een verwachte groei in inwoners van 30 procent. Om de groei in het aantal inwoners op te vangen, is er in Utrecht een start gemaakt met het herontwikkelen van binnenstedelijke gebieden. De Merwedekanaalzone, met meer dan 8000 woningen de grootste van deze gebieden, is uniek in deze herontwikkeling vanwege zijn autovrije karakter. Dit zorgt er niet alleen voor dat Utrecht zich kan profileren als een stad met een duurzaam karakter, maar het zorgt er ook voor dat de wegen rondom het gebied niet nog verder dichtslibben. Aangezien een autovrije wijk nog niet eerder op een schaal als deze is gerealiseerd is het onzeker wat voor type mensen zich zullen vestigen in deze wijk en hoe de bereikbaarheid gegarandeerd wordt zonder het gebruik van de eigen auto.

Om meer inzichten te verkrijgen in deze onderzekerheden, richt dit onderzoek zich op het bepalen van de socioeconomische en transportgerelateerde aspecten van inwoners in autovrije wijken, alsook op een model om bereikbaarheid naar werklocaties te analyseren. Om dit doel te bereiken is een enquête verspreid in autovrije wijken in Utrecht (48 reacties), Amsterdam (87 reacties) en Groningen (69 reacties). Enerzijds richt deze enquête zich op het bepalen van deze socioeconomische en transportgerelateerde aspecten, terwijl anderzijds een gedeelte zich richt op het bepalen van de invloed van verschillende aspecten van een reis op de tevredenheid hiervan. De invloed van deze aspecten, zijnde reiskosten, reistijd in het voertuig, looptijd en wachttijd, zijn gebruikt om een model te realiseren dat bereikbaarheid in de Merwedekanaalzone kan evalueren in zowel de huidige situatie alsook in een situatie waarin maatregelen zijn toegepast in het transportnetwerk.

Resultaten, welke zijn vergeleken met een landelijke enquête van het Mobiliteitspanel Nederland, laten zien dat zzp‘ers en mensen werkzaam in loondienst met hoge inkomens en weinig kinderen vaker vookomen in autovrije wijken. Zoals verwacht is het autobezit laag in deze wijken, waarin de helft van de respondenten geen auto bezit. De andere helft van de respondenten bezit één auto, met als voornaamste redenen voor autobezit een betere mobiliteit of bereikbaarheid en een zekerheid om op elk moment te kunnen reizen. De grote hoeveelheid respondenten die op de fiets naar het werk reizen wijst op een zelfselectie die plaatsvindt in deze wijken. Opmerkelijk is ook het lage gebruik van deelmobiliteit, terwijl veel respondenten aangeven wel een mogelijkheid hebben deze te gebuiken. De houding tegenover deelmobiliteit versterkt dit resultaat, waarbij vooral een deelauto die ook gebruikt wordt door vreemden slecht wordt gewaardeerd.

Om de waardering van de reisaspecten in verschillende bevolkingsgroepen te vinden, is gebruik gemaakt van *latent class logit* regressie. Drie classes weerspiegelen de data het best, waarin de waarschijnlijkheid van het maken van een reis wordt verminderd door een toename in reisafstand (Class 1), reistijd buiten het transportmiddel (Class 2) en reizen in het algemeen (Class 3). Verschillen in leeftijd, inkomen, autobezit en huishoudgrootte bepalen de waarschijnlijkheid om in een bepaalde class te vallen. In de Merwedekanaalzone is te zien dat in de huidige situatie oudere leeftijdsgroepen en huishouden met hoge inkomens het minste aantal banen als bereikbaar ervaren, in tegenstelling tot gezinnen en huishoudens met lage inkomens. Fietsen, in vergelijking tot lopen richting OV-stations, resulteert in een verdubbeling van het aantal bereikbare banen. Het realiseren van enkel de fiets- en looppaden in het gebied resulteert in een relatief grote toename van het aantal bereikbare banen, veroorzaak door het ondoordringbare karakter van het gebied. Nieuwe loop- en fietsbruggen over het Merwedekanaal geven de grootste toename in baanbereikbaarheid, door het doorbreken van de natuurlijke barriere die het kanaal vormt. Geen verschil is te zien tussen de twee voorgesteelde tramroutes, hoewel dit afhankelijk is van de herkomstlocatie die wordt gebruikt in het model. Het upgraden van station Lunetten vergroot bereikbaarhid niet. In vergelijking met andere gebieden die mogelijk worden gerealiseerd als autovrij in Utrecht presteerd de Merwedkenaalzone gemiddeld op het gebied van bereikbaarheid naar banen, waarbij de nabijheid van treinstations voornamelijk belangrijk is in het bepalen van bereikbaarheid naar werklocaties.

Extended summary

Utrecht is one of the fastest growing cities in the Netherlands, with a 30% expected increase in residents in 2040. To facilitate this increase in inhabitants, the municipality has designated areas in the inner parts of the city to be redeveloped. Within one of these areas in Utrecht, the Merwedekanaalzone, a large-scale car-free development area with over 8000 residences has been proposed. Not only does this contribute to the level of healthy urban living that the municipality strives for, but it also aims to relieve the already stressed car transport system around the area.

As the Merwedekanaalzone is the first car-free development area in the Netherlands that is implemented on a scale like this, many uncertainties arise. First of all, it is unsure which type of persons will relocate towards this area. How do the persons that reside within a car-free area differ from a population in a traditional car-oriented neighbourhood, both in terms of socio-economic characteristics as well as their day-to-day travel patterns. Besides the differences regarding the inhabitants in a car-free development area, it is currently also unknown whether the Merwedekanaalzone and the transport system in and around the Merwedekanaalzone can provide sufficient accessibility for its inhabitants without the use of car transport. To improve accessibility by means of walking, cycling or public transport, various measures are proposed in and around the Merwedekanaalzone. As opportunities regarding other transport motives like shopping and education have been realised within the Merwedekanaalzone itself, especially insights regarding the effect on longer-distanced commuting trips and therefore job accessibility are important.

Aim of this research is to determine socio-economic and transport characteristics of potential residents in car-free development, as well as to develop an accessibility model that can evaluate job accessibility with respect to the preferences of the distinguished population groups in car-free development. To do so, a main research question and three sub-questions have been considered within this research.

What are the differences in socio-economic and travel characteristics in car-free development and what are the effects of transport infrastructure measures on job accessibility for different population groups?

1. How do individuals that opt on living in car-free neighbourhoods in the Netherlands differ from an average household in the Netherlands?
2. What is the current state of job accessibility for a multi-modal car-free transport option in the Merwedekanaalzone, considering the perceptions and preferences of different population groups?
3. What is the influence of various transport infrastructure measures on job accessibility of different population groups in the Merwedekanaalzone?

Literature review

Within the literature it is found that the implementation of a car-free development area is done using three different methods. Firstly, the limited access model restricts motorised traffic from entering the area. The Merwedekanaalzone is designed using a limited access model, with parking opportunities located at the edges of the area. Secondly, within the Vauban model no limitations are present regarding vehicle access. Instead, parking along the streets is restricted and dwellings have been realised without a parking driveway. Within this model especially, enforcement to guarantee a car-free environment is necessary. Thirdly, pedestrianised city centres are mostly used to convert an already area to a car-free area. Within these city centres public transport opportunities are often already present, providing sufficient accessibility for its inhabitants.

Several aspects that influence car ownership have been distinguished within the literature. These aspects can generally be divided into four different group. Firstly, transportation characteristics provide the opportunity to use transport modes other than private car transport. Important aspects when using other

transport modes are availability, provided accessibility, reliability, and level of service. Secondly, socio-economic characteristics in the form of age, income, two-parent households, presence of children, previous car ownership and life events such as a change in employment, residential relocation, cohabitation or the birth of a child are important explanations for a change in car ownership. Thirdly, characteristics of the built environment are influential to car ownership levels, although it is difficult to isolate the effect of a single characteristic. From the literature, urban density, diversity in the number of land uses, spatial design, distance to transit and demand management of the available parking spots are potentially influencing car ownership. Fourthly, individual taste and personal attitude towards different transport modes are important factors that are influencing car ownership, especially when habitual car usage is present within the daily travel patterns of individuals.

Methodology

The method used within this research entails two different components. Firstly, a survey is spread within three car-free residential areas in the Netherlands to approximate a population in car-free development areas and therefore find socioeconomic and transport characteristics. The locations in which the survey is spread are an already realised area within the Merwedekanaalzone (48 responses), the GWL Terrein in Amsterdam (87 responses) and the Ebbingekwartier in Groningen (69 responses). A revealed preference part within the survey determines socio-economic and trip characteristics of the inhabitants in car-free development, while a stated preference component in the form of a discrete choice experiment distinguishes the relative utility of different trip characteristics in a public transport trip. The utility of these trip characteristics is determined providing commuting trips from two hypothetical neighbourhoods that differ in terms of travel costs, in-vehicle travel time, access walking time and waiting time at the used public transport station.

Secondly, to analyse job accessibility in the Merwedekanaalzone as a case study area, a Geographic Information System (GIS) model is developed in which a location-based accessibility approach is used. Necessary components within this approach are first of all available jobs and the number of competitors in every destinating area, obtained with data from the Provinciaal Arbeidsplaatsen Register (PAR) and the Landelijk Informatiesysteem van Arbeidsplaatsen (LISA) regarding jobs, and data from the Centraal Bureau van de Statistiek (CBS) regarding inhabitants. A public transport network that includes the bus and tram network in the province of Utrecht, as well as the train network in the Netherlands is used to determine trip characteristics between the Merwedekanaalzone and the destinating areas. To account for access travel time as well as transfers between different public transport modes, walkable and cyclable streets are incorporated within the model. The output of the stated preference discrete choice experiment is used in combination with the obtained trip characteristics in the accessibility model to determine the probability of a certain individual perceiving a commuting trip between the Merwedekanaalzone and a destination to be acceptable.

Within the GIS model, job accessibility using public transport in the current situation in the Merwedekanaalzone is evaluated, while also the effect when implementing only the street network in the project area is evaluated. Furthermore, various transport infrastructure measures in and around the Merwedekanaalzone have been assessed being several bridges across the Merwedekanaal that are only designated for walking and cycling, tram tracks as proposed both by the authorities in Utrecht as well as by experts from Mott MacDonald and an upgrade of train station Lunetten to serve intercity trains both from the southern as the eastern parts of the Netherlands.

Survey results

The results of the revealed preference part of the survey show that (self-)employed persons and high-income households are more often present in the sample. By observing the household situation in car-free development areas, it can be noticed that children are less often present and instead couples without children can be found in these households. As expected, car ownership is low in these areas, with nearly half of the respondents not owning a car. In line with the literature, a reduction in car ownership from two to one car is noticeable. A possible explanation for this, which is also confirmed by some respondents, is that some inhabitants perceive the need to own a car to guarantee a certainty of travelling and to have a sense of control. Making it possible to obtain this sense of control using public transport modes would therefore make it possible to reduce car ownership even more, underlining the need for barrier-free travel using public transport.

Job commuting in the investigated areas is mostly done by bike, suggesting that respondents either choose to live close to their job or find a job close to their residence and that thus residential self-selection is present within these neighbourhoods. When the Merwedekanaalzone is realised, longitudinal research could be used to find differences in transport characteristics before and after moving to a car-free development area. Respondents that currently commute by car or train also prefer to commute by bicycle, which is confirmed by relatively lower satisfaction levels of these commuting modes.

Although shared cars are available within the areas and are often suggested as a solution in car-free areas, almost none of the respondents use any form of shared modes. This is endorsed by the attitude towards the different transport modes, with a shared car that is also used by strangers being negatively perceived compared to private cars. As the municipality considers shared modes to be an important replacement for incidental car usage in the Merwedekanaalzone, the relatively small usage of shared cars could become an issue and therefore more methods to stimulate shared car usage could be considered.

The results of the stated choice component of the survey have been analysed using latent class logit regression. Latent class logit regression is a derivation of the more commonly known multinomial logistic regression and is necessary due to the alternatives used in the discrete choice experiment not being inherently different. Three latent classes best described the data, determining the relation in utility between four different trip characteristics. These trip characteristics determine the probability to perceive a public transport trip to be acceptable, with respect to the individual preferences of an individual based on its socio-economic characteristics.

Within Class 1 especially characteristics that increase travel distance determine the disutility of a trip. In Class 2 total travel time mainly increases the disutility of a public transport trip. Class 3 represents the disutility of travelling in general, with all characteristics providing a lot of disutility to the trip towards a job location. Socio-economic characteristics that significantly influence the probability to belong to the different classes are age, household income, the number of cars owned and the number of persons in a household. An increase in age or income increases the probability to belong to Class 2, while an increase in the number of cars or persons in a household enhances the class probability of Class 1. Probabilities to belong to Class 3 remain low, with especially average income levels and an increased number of persons in a household determining the probability for this class.

A simulation that uses the distributions of socio-economic characteristics in the collected sample determines the average probability of a population group to belong to the different classes. Starters and families have a relatively high chance to fall in either Class 1 or Class 2, while senior adults have relatively higher chances to belong to Class 2 or Class 3. In line with the relatively low influence of costs on trip probability in Class 2, high-income households have a higher chance to belong to this class. Low-income households on the other hand can be found in Class 1 and Class 3 more often.

Accessibility results

From the developed accessibility model, results have been found regarding job accessibility in the Merwedekanaalzone. In a base scenario, the current situation before developing the project area, it can be clearly noticed that the Merwedekanaal acts as a barrier with increased travel times and travel costs to areas on the other side of the canal. Bus transport is the quickest form of transport from the Merwedekanaalzone in the current situation, as shortest travel times follow bus corridors instead of tram tracks. For longer distance commuting, train travel is the main mode of transport, with some of the major cities in the Randstad being reachable by public transport from the Merwedekanaalzone in around 60 minutes. Within the base scenario, senior adults and high-income households perceive the least number of job opportunities to be available, while families and low-income households perceive the most jobs to be accessibility. In case of a bike-and-ride scenario, job accessibility increases to almost twice the amount for all population groups compared to a walk-and-ride scenario. This addresses the importance of a dedicated cycling network in and around the Merwedekanaalzone, which can provide quick connections to train stations in Utrecht and thus increases accessibility significantly.

The measures proposed within the Merwedekanaalzone have been analysed regarding the perceived job accessibility they provide, being only realising the internal street network in the Merwedekanaalzone, an increased number of bridges across the Merwedekanaal, improvements to the tram network in Utrecht and the improvement of the train station of Utrecht Lunetten to facilitate intercity trains. Developing the Merwedekanaalzone while only realising the internal street network of the area already significantly improves accessibility. This increase is caused by the currently impenetrable character of the Merwedekanaalzone, which is greatly reduced if inhabitants can leave the area at multiple locations. Realising bridges across the Merwedekanaal results in the largest increase in job accessibility, as the barrier that is caused by the Merwedekanaal no longer exists in this situation. No notable differences between the two tram routes can be distinguished, with both measures providing an increased level of accessibility of 5 to 8 percent. However, if instead of an origin at the centre point of the Merwedekanaalzone an origin on the southern part of the Merwedekanaalzone is used when determining accessibility, more jobs are perceived as accessibility when considering the tram track that is proposed by Mott MacDonald. Upgrading Utrecht Lunetten to serve intercity trains has no influence on accessibility when implemented separately. This indicates that this train station is currently not used by inhabitants of the Merwedekanaalzone to commute to their job location. When a combination of measures is implemented in and around the Merwedekanaalzone, job accessibility is increasing only slightly. This suggests that there is an overlap in the provided accessibility between the different measures.

As the Merwedekanaalzone is not the only location in Utrecht that is potentially developed as being car-free development, the project area is compared with other areas in Utrecht that are either already planned to be car-free (Beurskwartier, Cartesius) or are possibly developed car-free in the future due to their proximity to train stations (Leidsche Rijn, Lunetten, Overvecht) or due to their proximity to job opportunities (Science Park, Papendorp). In contrast to these other areas, the Merwedekanaalzone provides average accessibility results. In areas that are located close to train stations, job accessibility is relatively high. In locations on the edges of Utrecht, in which a substantial number of job opportunities are present, accessibility is relatively low compared to the other locations. This implies that the transport network is of higher importance compared to the number of nearby job opportunities when determining accessibility. It should however be taken into account that job accessibility is not the only indicator that determines the suitability for car-free development, as many other could be important when determining this suitability.

Applications

Limitations regarding this research can first of be all be found within the collected sample. This sample approximates the population in a car-free development area as currently the Merwedekanaalzone is still mostly undeveloped. Therefore no validation or comparison with an actual car-free population is possible, giving no guarantee that this sample actually represents a population in a car-free development area. Secondly, as a stated preference method is used to determine the disutility that the trip characteristics provide, not the actual but rather the rational behaviour is captured within this experiment. Revealed preference data on trip characteristic evaluation or even a combination of revealed and stated preference data could better describe the behaviour of the respondents. Thirdly, simplifications are present within the accessibility model regarding the use of bus, metro and tram transport to locations outside of the Province of Utrecht. Also within the evaluation of the trip characteristics a simplification is necessary, as due to complexity of the choice experiment the trip characteristics could not be evaluated for every single public transport mode but instead for public transport in general. Finally, the accessibility model assumes a shortest path based on in-vehicle travel time and out-of-vehicle travel time. If instead trips with the highest probability of travelling can be incorporated within the model, accessibility could be captured more precisely.

With the results of this research, policy implications for the Merwedekanaalzone can be analysed. The effect of the different measures on job accessibility are analysed, which can be used by the municipality to provide car-free living for every inhabitant and thus promote healthy urban living. Potential barriers have been distinguished, being a relatively high level of car ownership in the observed areas and a low number of perceived accessible job opportunities for senior adults and high-income households. This provides a focus point for the municipality, as the decision to implement one or more of the measures results in different accessibility patterns. This research also provides a start for determining suitable locations for car-free development in urban areas. Other aspects that determine this suitability can be incorporated within the accessibility model, providing insights whether a location is suitable to develop as car-free.

Future research regarding accessibility in car-free development could be focussed on better approximating the residents in car-free development. Especially residential self-selection which in this research was found to be possibly present in this research could be investigated, by making use of a longitudinal research that compares respondents before as well as after their relocation to a car-free development area. Another interesting research direction is the relatively high number of cars in the investigated areas. Future studies could help in further examining how to obtain a similar certainty of travelling using public transport modes or a form of shared transport, which are currently the points of concern in the investigated car-free development areas.

1 Introduction

Within this section, the content of the research will be introduced. First, an introductory background to the topic is given, followed by a formulation of the problem and objective of the research. Then, relevancy of this research for involved associated groups is described. Next, the approach to this research is specified, after which the structure of this report finalizes this section.

1.1 Background

Utrecht is one of the fastest growing cities in the Netherlands. It is expected that in 2040 over 450.000 inhabitants will reside within the city, which is an expected grow of around 30% (Gemeente Utrecht, 2020a). As the municipality strives to obtain healthy urban living for their inhabitants, the environment needs to suit this way of living as well. To achieve this, a combination of development area on the outer edges of Utrecht and a compact renewal of the inner parts of the city has been proposed.

Within one of these inner-city areas, the Merwedekanaalzone, the municipality strives to achieve healthy urban living by establishing a car-free area in which individual car use is discouraged and instead more sustainable transport modes are promoted among the inhabitants. This kind of development is relatively new in the Netherlands, with the Merwedekanaalzone being one of the first areas to reduce car ownership on a large scale throughout an entire neighbourhood. However, besides promoting healthy urban living, there is another reason for the municipality to introduce car-free development. As the Merwedekanaalzone is located close to the city centre, there is already a large amount of urbanisation in zones around the area. This dense urban environment produces a lot of traffic in and around the area. Developing a traditional residential area in the Merwedekanaalzone will stress this transport system even more, resulting in a situation in which accessibility of adjacent zones cannot be ensured (Gemeente Utrecht, 2018).

To increase mobility of the inhabitants in the area, several transport infrastructure measures have been proposed in and around the Merwedekanaalzone. This approach focuses on enhancing the travel component of a trip, aiming on a reduction of travel time and an increase in transport capacity. On the contrary, to ensure accessibility within the area, necessary facilities like educational and commercial services will be available within the Merwedekanaalzone itself. For long-distance travel purposes like commuting trips, ensuring accessibility is more difficult. By increasing mobility for inhabitants in the Merwedekanaalzone the municipality tries to guarantee accessibility when using transport modes other than car transport (Gemeente Utrecht, 2020b). Nevertheless, realising the Merwedekanaalzone as a car-free neighbourhood brings many challenges and a lot of uncertainties.

1.2 Problem and objective

As a large-scale car-free development area like the Merwedekanaalzone has not yet been realised within the Netherlands, a first problem arises in the uncertainty about the type of inhabitants that will reside within the neighbourhood. As potentially residential self-selection will take place, it is necessary to get insights about the differences in characteristics of these inhabitants to successfully realise a car-free neighbourhood. Inhabitants that deliberately decide to live car-free are likely to be interested in living in the Merwedekanaalzone, while it is also possible that residents are interested in living in the Merwedekanaalzone because of the excellent location within Utrecht. These inhabitants could perhaps be less interested in the car-free concept, persisting to use individual car transport as their primary means of transport since there are no restrictions to car ownership. In any case, the resulting demographic population is likely to be different from a standard residential neighbourhood due to the car-free intentions that the municipality has. Information about these residents is necessary in finding their travel preferences in a car-free neighbourhood.

Moreover, the effectiveness of the proposed transport infrastructure measures is unknown. The municipality tries to ensure accessibility for every inhabitant of its city, by proposing a set of car-free transport measures that enhance walking, cycling, public transport and shared travel modes. It is unsure whether these solutions are effective for the different population groups that reside in car-free areas, as well as whether these solutions provide the same amount of accessibility for every population group. By researching the change in accessibility, specifically in contrast to the different preferences that the different population groups have, the effectiveness of the proposed (combination of) measures can be investigated. This provides a starting point for necessary measures in car-free development, contributing to the realisation of the healthy urban living that the municipality of Utrecht strives for.

Based on the stated problem and objective, the following main research goal is composed:

Develop an accessibility model in car-free development that is able to evaluate trip characteristics and job accessibility with respect to the travel preferences of different population groups.

The results of this research provide an advice, in which the effectiveness of the different measures will be elaborated on. This gives the possibility to implement various measures that proved to be effective, as well as find alternative solutions that are necessary to guarantee accessibility for all inhabitants in the Merwedekanaalzone. It also provides a solid basis for future realised car-free development areas, for which the Merwedekanaalzone is an important reference project to draw conclusions on. The framework that is constructed within this research can be used within these areas to determine the suitability to realise a car-free residential within these neighbourhoods.

1.3 Relevancy

First, the University of Twente and other academic institutions benefit from this research with extensive knowledge on the needs of different population group in car-free development areas. Within the literature, a lot of research has been done on the different types of car-free development areas and the (dis)advantages of the different implementations in terms of sustainability and car ownership reduction (Melia et al., 2013; Nobis, 2003; Ornetzeder et al., 2008). However, the change in accessibility and in mobility patterns that comes with the realisation of car-free development has only been minimally researched. The framework and outcome of this research could be used in future car-free development areas, to determine appropriate measures that fulfil the needs of the residents. Furthermore, there is little to no information about the characteristics of these population groups in the Netherlands specifically, as well as about their preferences regarding the different sustainable transport modes that are often implemented in car-free environments.

Secondly, Mott MacDonald is contributing to this thesis in the form of knowledge and supervision. By exploring the different accessibility needs for inhabitant groups in car-free development within this thesis, Mott MacDonald can obtain new insights to develop the transport network in the direct surroundings of the Merwedekanaalzone. The company is involved in studies to determine the effectivity of a new rapid transit line next to the project area, thus especially benefiting from knowledge on the effectiveness of the different measures within a car-free development area.

Thirdly, the municipality of Utrecht profits from this research. The municipality promotes healthy urban living, in which transport should benefit to physical, mental and social wellbeing (Gemeente Utrecht, 2018)**.** It strives for guaranteed mobility for all its inhabitants, making sure that every person can travel comfortably throughout the city. This thesis contributes to providing this guaranteed mobility, as it is focused on mapping the individual needs of the inhabitants. With the outcomes of this thesis, the municipality gets acquainted with the different transport needs that arise when car-free development is being realised and how the different transport solutions contribute to these needs. Being able to distinguish these needs, the municipality can strengthen its mobility supply to the demands of the inhabitants of Utrecht.. Also, other municipalities that plan on implementing a car-free residential area within the built-environment can also use the outcomes of this research. This gives these municipalities the possibility to successfully provide car-free living as well.

1.4 Research approach

To achieve the main research goal, a main research question is composed.

What are the differences in socio-economic and travel characteristics in car-free development and what are the effects of transport infrastructure measures on job accessibility for different population groups?

In order to find an answer to the main research question, several sub-questions have been defined. These sub-questions aid in tackling the problem step by step, giving a structured and intuitive way of analysing.

1. How do individuals that opt on living in car-free neighbourhoods in the Netherlands differ from an average household in the Netherlands?

A first stage within this research is related to the type of persons that possibly inhabit a car-free development area. As it is currently unknown which type of persons are more or less likely to live car-free, it is important to determine any differences within their socio-economic characteristics, as well as within their daily travel pattern.

2. What is the current state of job accessibility for a multi-modal car-free transport option in the Merwedekanaalzone, considering the perceptions and preferences of different population groups?

In contrast to car transport, within a multi-model trip many factors, like walking and waiting time, are potentially influencing accessibility. A first analysis is focused on identifying which of these factors are influencing accessibility and how much influence each of these factors has on the probability to make a commuting trip when living in a car-free development area. This influence will be determined for different population groups, as accessibility can be perceived differently across individuals based on the relative importance that this individual gives to the trip characteristics. After finding accessibility indicators and the relative importance of trip characteristics within different population groups, accessibility can be evaluated in the Merwedekanaalzone as a case study. The relative importance of trip characteristics for different population groups is used in combination with a Geographic Information System (GIS) model, to evaluate perceived job accessibility within the Merwedekanaalzone when no extra measures are implemented.

3. What is the influence of various transport infrastructure measures on job accessibility of different population groups in the Merwedekanaalzone?

After a base scenario is constructed and job accessibility is found for different population groups, measures as proposed in and around the Merwedekanaalzone that ought to increase accessibility in the Merwedekanaalzone can be processed within the analysis. These measures provide a reduction in on of the influential trip characteristics, and thus increase mobility using a car-free transport mode. The effectiveness of a single measure as well as a combination of measures will be evaluated, analysing whether job accessibility increases for all population groups or whether certain population groups will benefit unequally in comparison to other groups.

1.5 Reading guide

The remainder of this report is structured as follows: An overview of the current literature on car-free development, car ownership and accessibility provided in Chapter 2. The explanation of the case study and the used methodology to find answers on the proposed research question and sub-questions is explained in Chapter 3. The survey results and the output of the regression model are described in Chapter 4. Chapter 5 covers the results of the accessibility analysis and the effectiveness of the provided measures in a car-free development area. Finally, Chapters 6 and 7 provide a discussion and further recommendations on the outcomes of this research, as well as conclusions to this research.

2 Literature review

2.1 Car-free development

Within this section, the concept of car-free development will be further elaborated on. First, different definitions will be explained, followed by an evaluation of advantages and disadvantages of car-free development. Finally, different forms of car-free development will be evaluated, as well as various examples for every form. Findings from earlier implemented car-free development areas will be evaluated, to be able to compare these with the results of this research.

2.1.1 Definition and advantages of car-free development

As the term car-free development has been used in multiple ways to refer to an area in which the number of car trips has been reduced, it is important to define car-free development in a consistent and perspicuous manner. After evaluating several examples of car-free development throughout Europe, Melia et al. (2011) define car-free development to be residential or mixed land-use development which:

- Provides a traffic-free or nearly traffic-free immediate environment.
- Offer limited or no parking opportunities separate from the residence.
- Are designed to enable residents to live without owning a car.

While car-free implies that cars are not present at all in an area, it can be clearly noticed from the enlisted criteria that to some extend car traffic and car ownership is allowed. The term car-free thus relates to a state in which the presence of cars within the neighbourhood is reduced, though not completely prohibited. Instead, residents in car-free development are discouraged in their car ownership and to some extend motorised vehicles are excluded from the area. These two aspects are closely related to each other, as exclusion of vehicles indirectly leads to a reduction in car ownership and vice versa (Melia, 2014). As a consequence, less land is present for roads and parking places, car use is reduced and sustainable and healthy transport modes are used more frequently.

Figure 2.1 provides a schematic overview of the benefits of car-free development from different perspectives within different spatial areas. Whereas in a completely car-free development area these consequences would apply, in a partially car-free development area these benefits would not normally apply or apply to a lower extend (Melia et al., 2011). Benefits might be present due to a lower car ownership, however environmental and quality of life benefits are dependent on the exclusion of vehicles in the area (Ornetzeder et al., 2008). Findings from Melia et al. (2013) and Parkhurst (2003) support this statement, as they found that low car development endorsed the use of public transport, the establishment of local services and an increase in active travel compared to conventional development. However, this study also found little evidence on the improvement of the local environment. On a transportation basis, Melia et al. (2011) found that car ownership reduced, even in areas in which parking spots were present for residents. In many cases, households reduce the number of cars from multiple cars to only one. This suggests that in earlier stages a household owns multiple cars to be used in incidental cases, whereas in a later stage a single car proved to provide sufficient accessibility.

Disadvantages of car-free development are mainly present within the attitude towards car-free development. Melia et al (2013) found in their survey in Dorset, a low-car development area, that the most frequently cited problem was a lack of parking and that conflicts between neighbours arose over the limited number of parking spaces. On the contrary, other inhabitants were annoyed by the fact that areas designed as home zone could rarely be used by children and were in most cases occupied by parked cars. This indicates that a mixed kind of inhabitants occupy car-free and low car development. On the one hand inhabitants that deliberately move to a car-free neighbourhood and decide to live car-free. On the other hand, inhabitants that have no interest in reducing their car use whatsoever. These inhabitants live in a car-free neighbourhood due to the excellent location or the type of dwellings within the area. It is less likely that these inhabitants will give up car ownership, thus further congesting the often already stressed road network.

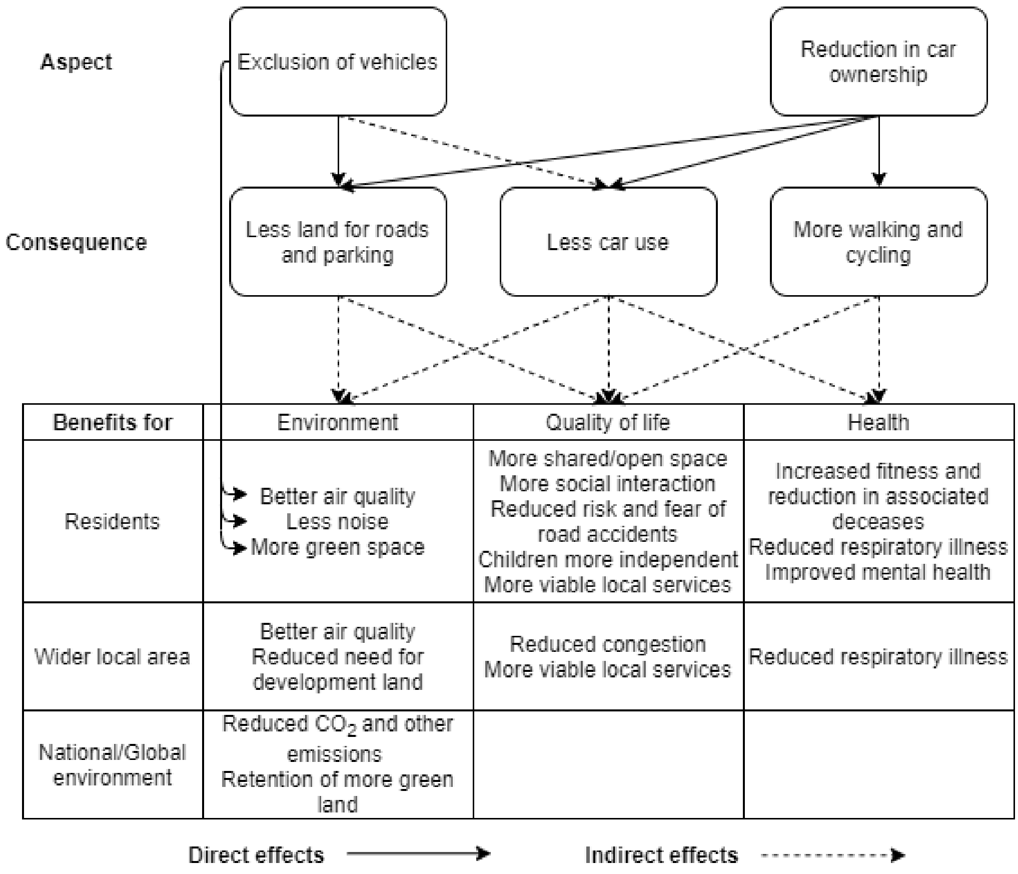


Figure 2.1: Benefits of car-free development (Adapted from Melia (2014))

2.1.2 Examples of car-free development

Over the last decades, several large-scale car-free residential areas have been constructed throughout western Europe. Although there are still differences between cases within each type, mainly three different types of car-free development can be distinguished: the Vauban model, the Limited Access model and the pedestrianised centres with significant residential population (Melia, 2014). Within these areas obtaining a completely car-free development area did not prove to be possible, however by implementing one or multiple car-reducing measures significantly reduced car ownership.

Vauban model - As one of the first car-free areas in Europe, the neighbourhood of Vauban in Freiburg was realised in 2006. The main distinction of this model in comparison to the other models is that no physical restrictions are present to prevent motorised vehicles from entering the neighbourhood. Instead, Vauban can be seen as a neighbourhood that is free from parking places, to reduce the number of cars in the area. Vehicles are allowed on the streets within the neighbourhood, while parking along the streets is not permitted. As parking adjacent to the residences is not possible, hardly any parked vehicles can be seen on the streets in Vauban (Melia, 2014). Any resident within Vauban is forced to sign an annual declaration in which they state whether they own a car or not. Car owners that live within the area are obliged to buy a parking spot within one of the car parks on the periphery of the area, which can be seen as a negative incentive for residents to own a car.

Although car ownership is discouraged among residents in Vauban, car ownership showed to be surprisingly high at 54% (Melia, 2006). The share in car trips in the neighbourhood however remains low, with only 16% of all trips being made by car. Some car owners within Vauban have tried to circumvent the rules regarding car ownership and car parking. Cars have been registered on relatives' names, private arrangements to park a car have been made with residents just outside the car-free area or cars have been parked on land classified as undeveloped (Melia, 2006). Besides, Nobis (2003) found that although parking cars along roads has been restricted, car owners neglected these rules and parked along the street anyway. This indicates that discouragement of car ownership is not enough to achieve complete car-free development and instead also encouragement to dispossess a car is necessary.

Limited Access model - Whereas the Vauban model does not restrict motorised access to the area, most examples of car-free development avert motorised traffic from entering the area. The Limited Access model is mostly used in car-free development that is of a smaller scale, such as the GWL Terrein in Amsterdam and Stellwerk 60 in Cologne (Melia, 2014). Since the neighbourhoods are of a smaller scale, entrances to the dwellings are relatively close to the perimeter of the area. Removable objects are used to restrict cars from entering the area, making it possible for emergency vehicles or removal vans to reach the residences (Melia et al., 2011). Besides restricting cars from entering the area, car parking at the periphery of the GWL Terrein has been provided for a ratio of only 0,2 per household.

Pedestrianised centres with significant residential population - Whereas the Vauban model and the Limited Access model are mostly used in newly realised car-free development, pedestrianised centres are often fitted to suit a significant number of residents without the use of cars in an already existing neighbourhood (Melia et al., 2011). Most of these areas are largely comprised by commercial development, accompanied by a proportion of residential housing located on top of the commercial dwellings or dwellings that were already present when the pedestrianised centre was realised.

The shift from car-oriented city centres towards city centres that are focussed on cycling and walking is already noticeable for decades, after cars flooded the city in the middle of the previous century. As often well-established public transport connections are present within these areas, no extra measures need to be taken to ensure accessibility for inhabitants of these areas. An example can be found in Groningen, the Netherlands, in which the city centre is partially pedestrianised and completely closed for through traffic (Melia et al., 2011). Through traffic is instead guided via an inner ring road that entails the pedestrianised centre. Cyclists are allowed on nearly half of the streets within the centre, diminishing the number of encounters between cyclists and pedestrians.

2.2 Aspects influencing car ownership

To better understand the decision of a household whether or not to own a car in a car-free neighbourhood, it is important to study the attributes that influence car ownership in general. Gaining information about these attributes gives the possibility to study the presence of these attributes within a car-free development area as well as the importance of these attributes for households that live in these areas.

Attributes that relate to the number of cars that are present in a household are modelled in two distinctive ways in the literature. Car ownership can be analysed on an aggregate level, determining the number of cars at a zonal level. Alternatively, car ownership is being determined at a disaggregate level, relating the number of cars to household specific characteristics and aggregating over the number of households. As disaggregated models are better capable of determining the relationship between car ownership characteristics and the actual level of car ownership, disaggregate models have become the preferred approach when finding attributes that determine car ownership (Bhat & Pulugurta, 1998). Explanatory variables that form the basic structure of disaggregate models of car ownership can be divided into two types. First the household characteristics and characteristics that are influenced by the built environment and secondly the transportation system (Potoglou & Kanaroglou, 2008). Also, individual characteristics such as attitude and habit are identified as a third group.

2.2.1 Transportation characteristics

Providing the opportunity to use other transport modes is an important factor in lowering individual car ownership (Clark, Chatterjee, et al., 2016). Providing higher accessibility using these transport modes also results in a higher usage of that transport mode (Van Acker & Witlox, 2010). Rajamani et al. (2003) found that it is more likely for people to walk or bike to recreational activities, if destinations are more easily accessible by foot or by bike. X. Cao et al. (2007) discovered that an increase in accessibility by other modes, thus reducing travel times for one or more components of the trip, turned out to be an important factor in reducing car ownership. Accessibility and estimations of accessibility are further elaborated on in Chapter 2.3.

In their study, both Nijland & van Meerkerk (2017) and Martin et al. (2010) found that carsharing users are not only more likely to give up car ownership but also reduce their travel distance significantly. Liao et al. (2020) found evidence for a reduction in car ownership among respondents that are oriented towards car sharing, which respond to be willing to give up their car even when car sharing opportunities cannot replace most of their car trips. Interestingly, in the same study, increasing the availability of shared cars (modelled in terms of a difference of up to 30 minutes between the available time slot and the ideal time) seems to have little to no effect on the extent of reducing car ownership. This indicates that having the certainty of travelling by shared car is not remarkably important for respondents, whereas this is often a prioritised attribute for people to adhere to individual car use over shared or public transport modes.

Lastly, level of service of a public transport or car sharing service is an influential factor to attract car users. Redman et al. (2013) identified service quality attributes within public transport to either be a physical attribute (reliability, frequency, travel time, price etc.) or a perceived attribute (comfort, safety, convenience, attractiveness etc.). Within these categories, attributes that have been found to be most critical in customer satisfaction are price, travel time, reliability and operating frequency (Andreassen, 1995; Eboli & Mazzulla, 2008; Hensher et al., 2003). In car-free development areas especially, it is important that these services are present prior to the first residents moving to this area. Within the neighbourhood of Vauban, Nobis (2003) found that due to public transport services not being present at the very beginning, car ownership remained high and it was more difficult for these household to give up car ownership at a later moment.

2.2.2 Socio-economic characteristics

Car ownership differs greatly throughout population. Whereas among the population under the age of 50 car ownership is decreasing, among the older generations car ownership is increasing (Kampert et al., 2017). Especially among young adults, changes in car ownership are caused by factors such as a change in lifestyle (increased singlehood, postponement of parenthood), economic insecurity and the upcoming of e-communication (Goodwin & van Dender, 2013; Oakil et al., 2016). This has caused young adults to be the population with the largest decline in car ownership over the past decades.

Other than age, several other factors can be distinguished. Obviously, driving license availability is a strong predictor of car ownership level changes (Clark, Chatterjee, et al., 2016). Besides, Oakil et al. (2016) state that the presence of children is increasing car-dependency within a household, along with two-parent families having a higher probability of owning a car. A possible explanation for this is that families with children have a more complex travel pattern, which are more constrained in time and place compared to families without children (Potoglou & Kanaroglou, 2008). Nolan (2010) found that when households previously owned a car, this is a strong determinant for current car ownership. This is in line with the previous statements on habits in transport, causing difficulties to give up car ownership.

Other sources in the literature do not specifically distinguish certain socio-economic or household characteristics that are currently present, but rather analyse the life events within a household that determine the level of car ownership. A life event can be seen as transition points or moments of change in which people are likely to be the most open to changing habitual behaviour (Clark et al., 2014). Changes in employment, residential relocation, cohabitation and child birth can be seen as life events that potentially cause a change in satisfaction of the current car ownership level and a desirable alternative (Clark, Chatterjee, et al., 2016; Clark, Lyons, et al., 2016).

2.2.3 Built environment characteristics

It is difficult to determine the exact relationship between the built environment and the preferred mode of transport. Ewing & Cervero (2010) state that the combined effect of the characteristics within the built environment can potentially be large, however in the same study they found that none of the individual characteristics have an influential impact on travel behaviour. Nevertheless, characteristics from the built environment that are potentially influencing travel behaviour will be discussed separately, which can be scaled under the 6D aspects (Ewing & Cervero, 2010). As destination accessibility, one of the 6D aspects, is closely related to transportation characteristics, this aspect has been left out as an aspect in this section and is instead discussed in a later section of this chapter.

Density - Within the Netherlands, Oakil et al. (2016) found that the level of urbanisation in which a residence is located significantly lowers the level of car ownership of a household. Although the influence being much stronger for certain household groups than for other, this indicates that the different characteristics that come with a high urbanisation level provides suitable alternatives to driving. Public transport and a high-quality cycling network are widely available in areas with high urbanisation levels, while travel distances are also smaller as activities are more commonly present and less sprawled in contrast to rural areas.

Diversity - Increasing the number of different land uses is a good indicator to influence travel demand. Similar to spatial density, increasing the diversity in an area decreases travel distances between activities. Multiple indicators can be used to measures diversity, such as a ratio in which the number of jobs is related to the number of residences (Ewing et al., 1994), a similarity index that measures the land uses present within the surroundings of a person or an entropy index that analyses the degree of balance among multiple land use types (Kockelman, 1997).

Design - The spatial design of a neighbourhood influences travel behaviour as they differ in terms of density and diversity, but designs can also be orientated towards a specific transport mode. Design aspects that are negatively influencing travel behaviour of car users and instead encourage walking and cycling are small block sizes, a complete sidewalk system, the absence of cul-de-sacs and limited residential parking (Van Acker & Witlox, 2010). Other enhancements that increase walking and cycling and thus potentially favour the quality of the trip are attractiveness of the trip (greenery, appearance, variety in housing styles) and safety of the trip (low traffic, separated biking and walking lanes) (Cao et al., 2007). Meurs & Haaijer (2001) however found that design characteristics are only influential in trips made for shopping, social or recreational purposes. They state that commuter traffic is more likely to be influenced by personal characteristics.

Distance to transit - As private car ownership gives the possibility to travel from almost every origin to destination, it is important to maintain this possibility when making use of other transport modes. Chatman (2013) identified an increase in car ownership in households further away from rail stations. De Gruyter et al. (2020) support this finding, as in this study not only a decrease in average car ownership but also an increase in households with zero cars is found in areas close to the public transport system. Together with the in-vehicle travel duration, travel time from the residence to the departing transit station and from the arriving transit station to the destination comprise the total travel time for an individual.

Demand management - Finally the availability of vehicle parking within urbanised areas plays a role in car ownership. Demand management or parking management refers to parking facility supply, price and regulation. Solutions that reduce car ownership and car use are efficient parking prices, unbundling in which renting parking space is separated from building space and financial compensation for travellers who use non-car modes that is equivalent to parking subsidies provided to motorists (Litman, 2010). Within their case study, Weinberger et al. (2009) found that differences in car ownership were likely caused by parking availability in the proximity of the residence and were less likely to be caused by other spatial characteristics.

Within the Netherlands and in Utrecht specifically, the influence of built environment characteristics can be found in Figure 2.2 (CBS 2016, 2019). As seen in the figure, car ownership is negatively related to urbanisation rate. This indicates that the different built environment characteristics influence car ownership as described in this section.

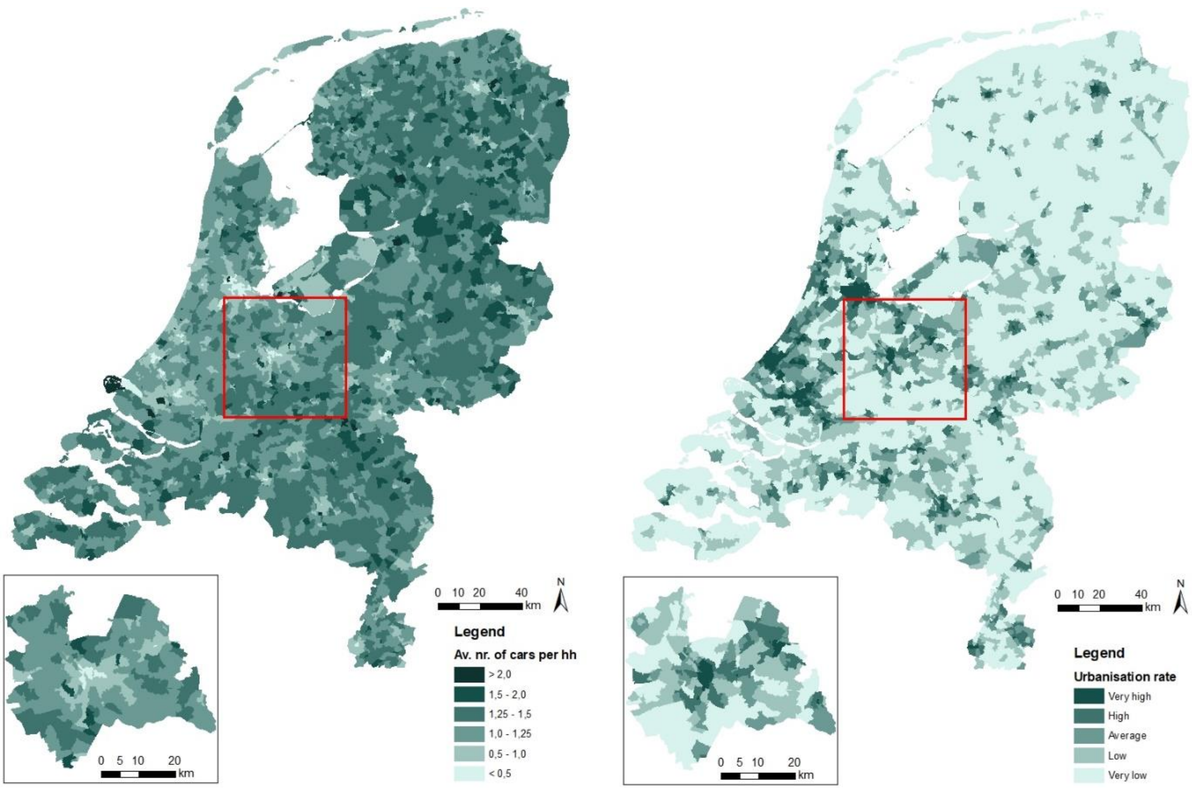


Figure 2.2: Car ownership and urbanisation rate (Adapted from CBS (2016, 2018))

2.2.4 Individual characteristics and attitude

Besides transportation, socio-economic and built environment characteristics, individual perspective towards car use is also an important factor influencing car ownership. As car ownership can be linked to a strong commitment to car use and an undervaluation of alternative transport modes, car owners often maintain their level of car usage (Tao et al., 2019). Besides, Clark, Chatterjee, et al. (2016) find that once a car is acquired, the car becomes a necessity and individuals are less likely to dispose of their car. Also, in many societies a car is perceived as superior to other transport modes both in terms of status and attachment (He & Thøgersen, 2017). In addition, as car ownership often has a positive relation with income level, public transport could be associated with a low-income solution and therefore could be seen as inferior to individual car use (Bamberg et al., 2003). These attitudes towards owning a private car increase car use and cause an avoidance of using alternative transport modes.

Residents that are currently using their individual car to travel from origin to destination, have often been doing so for a long time and have a habit in travelling individually by car. Thus, even when utilised costs of other transport modes are lower than those of a private car, drivers still choose to use a private car due to past experiences or travel habits (Gärling & Axhausen, 2003). Besides, providing sufficient transportation options gives young people the opportunity to postpone their car ownership or complete reduce the desirability of owning a car (Liao et al., 2020). This population group is more inclined towards new transport modes and is less likely to have a habitual travel choice,

Within their study, X. Cao et al., (2009) investigates whether neighbourhood design independently influences travel behaviour or whether preferences for travel options affect residential choice. The study identified that neighbourhood design and travel attitudes directly influence on the choice of residential neighbourhood, which then subsequently influences travel behaviour. Also, the authors find influence on car ownership as well as driving and walking behaviour even after influences caused by the built environment are accounted for. This could also be the case in car-free development areas, in which it is expected that due to residential self-selection a population will be present that favours sustainable transport modes and are less likely to own a car. To determine whether residential self-selection is present, longitudinal studies are necessary. Within these kind of studies repeating analyses that include individuals that relocated in between different analyses are needed, to control for their individual preference towards a certain area or neighbourhood (Heinen et al., 2018).

2.2.5 Summary car ownership aspects

As a conclusion, the four characteristic groups and their attributes can be found itemized in Table 2-1. Within this table it can be noticed that most transportation characteristics have a negative relationship with car ownership, while all socio-economic and individual characteristics have a positive relationship with car ownership. Within the built environment mixed influences can be distinguished, however it must be noted that the built environment is a very broad aspect.

Table 2-1: Influential factors of car ownership

Characteristic	Attribute	Source(s)	Relationship with car ownership
Transportation	Number of other transportation options	(Liao et al., 2020)	Negative
	Accessibility of other transport modes	(Cao et al., 2007)	Negative
	Car sharing options	(Martin et al., 2010; Nijland & van Meerkerk, 2017)	Negative
	Service quality other modes	(Redman et al., 2013)	Negative
Socio-economic	Age	(Kampert et al., 2017)	Positive
	Driving license	(Clark, Chatterjee, et al., 2016)	Positive
	Number of children/parents in household	(Oakil et al., 2016; Potoglou & Kanaroglou, 2008)	Positive
	Income	(Goodwin & van Dender, 2013)	Positive
Built environment	Urban density	(Oakil et al., 2016)	Negative
	Diversity of land use	(Ewing et al., 1994; Kockelman, 1997)	Negative

Characteristic	Attribute	Source(s)	Relationship with car ownership
	Walkable and cyclable design	(Van Acker & Witlox, 2010)	Negative
	Distance to transit	(Chatman, 2013; De Gruyter et al., 2020)	Positive
	Vehicle parking management	(Litman, 2010; Weinberger et al., 2009)	Positive
Individual	Previous car ownership	(Clark, Chatterjee, et al., 2016)	Positive
	Commitment to car usage	(Tao et al., 2019)	Positive
	Habit using a private car	(Gärling & Axhausen, 2003; Liao et al., 2020)	Positive

2.3 Accessibility

Accessibility can be considered as the combination between the transportation network and the spatial distribution of activities. The level of accessibility can be increased when either the transportation network causes lower travel costs between origins and destinations or when the number of spatial activities within the reachable range increases. Within accessibility it is not only important that accessibility is measured correctly, but it is also important that accessibility measures are intuitive and communicable. Communication especially between different fields of expertise could cause problems. Straatemeier & Bertolini (2008) state that for land use planners, who think in terms of places and activities, and transportation planners, who think in terms of networks and flows, it is difficult to communicate between each other. When calculating accessibility, results should thus give correct information but also an efficient output that is intuitive and understandable.

When defining accessibility as a concept, different definitions are present. Páez et al. (2012), define accessibility as the combination of cost of travel and the quality/quantity of opportunities. Straatemeier & Bertolini (2008) complement this statement, by relating accessibility to the transport system and the land use system for different travel motives. Geurs & van Wee (2004) include two other components to accessibility, as they also include variations in term of time and individual characteristics. A total of four components can be concluded:

- The land-use component consists of the combination of opportunities on every destination and the demand for these opportunities on every origin, along with a competition effect based on the amount of demand and the capacity of opportunities.
- The transportation component comprises the system that makes it possible for a person to travel between an origin and a destination. Trips made by different transport modes are being expressed in travel time, travel costs and travel effort. Also supply and demand is present within this component, in the form of travel characteristics and the number of passengers.
- The temporal component contains constraints about the travel needs of passengers and travel opportunities of transport modes on different times of the day and different days of the week. Including a temporal component is especially important in terms of accessibility by public transport, as frequency of service and routing schemes are not always in line with travel preferences of transport users (Stępniak et al., 2019).
- The individual component reflects on the socio-economic characteristics of individuals, that influence access to different transport modes and the number of available opportunities that match their qualifications. These characteristics can be divided into needs, abilities and opportunities, and differ depending on the background of the individual.

It can be concluded that every component is necessary in defining accessibility. By considering these components, measures can tackle a large portion of the lack of accessibility to opportunities for an entire area. Studies however also provide perspectives on the different concepts of accessibility from the point of view of a policy maker and a transport user. Within the literature, a distinction can be made between normative and positive accessibility (Páez et al., 2012). Normative accessibility is defined in terms of how far people ought to travel, the expected travel costs that are reasonable or the maximum allowed travel costs. Positive accessibility on the other hand defines the actual travel behaviour of the transport user, varying between individuals. Differences in accessibility between the two perspectives could be present, based on individual preferences and acceptance of travel resistances. Another, relatively similar concept of accessibility is provided by Cascetta et al. (2016) and Lättman et al. (2018). They state that there is an important difference between objective and perceived accessibility in determining the number of available opportunities. Objective accessibility in this case is determined using the number of reachable opportunities, perceived accessibility is established using the opportunities that satisfy the needs of the person. Total accessibility is therefore only measured by using the overlap of the two, which are the available opportunities that are reachable and satisfy one's needs. Figure 2.3 provides a schematic overview of the available opportunities that Cascetta et al. (2016) suggest to use when determining accessibility.

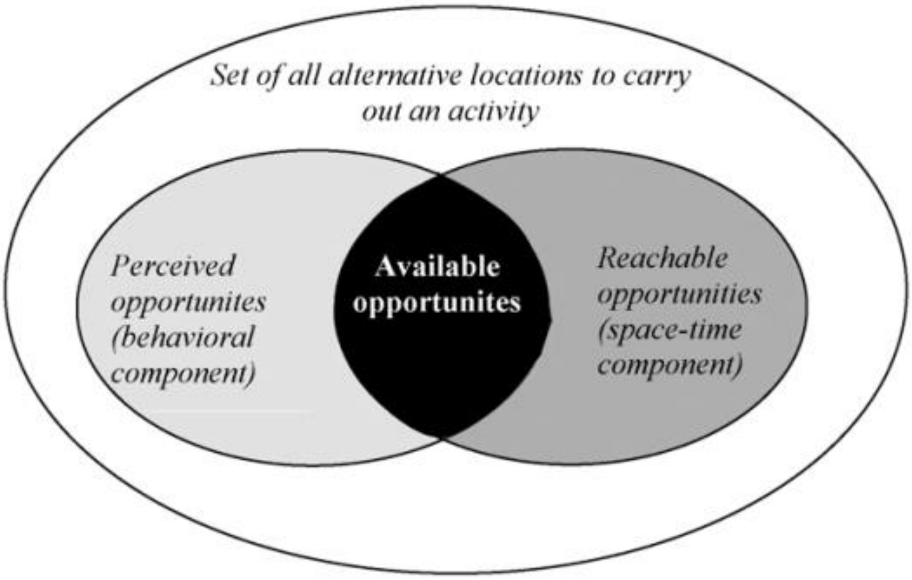


Figure 2.3: Accessibility using perceived and reachable opportunities (Cascetta et al., 2016)

Measures can however also be divided into different groups, that all comprise one or more earlier described components (Geurs & van Wee, 2004). As potentially not all components can be included within a certain measure, not all measures are competent in determining accessibility in a correct way.

2.3.1 Infrastructure-based accessibility

Infrastructure-based measures evaluate accessibility in terms of performance of the transport infrastructure by considering a specific aspect such as congestion level or average travel speed. These types of measures favour the state of the transport system itself, however infrastructure-based measures do not consider any of the components other than the transportation component. As infrastructure-based measures do not take into account land-use components, Geurs and van Wee (2004) describe that both the effect of transport strategies on land-use as well as the effect of land-use strategies on accessibility are not incorporated within these types of measures.

2.3.2 Location-based accessibility

Location-based measures analyse accessibility by using the spatial distribution of activities and how much of these activities can be reached within a certain amount of time. Location-based measures can be scaled based on the complexity of the model. Specific accessibility definition and distance decay functions for the different models have been presented by Song (1996).

Cumulative-opportunity calculations simply measure the travel distance or travel time between an origin and a destination. When multiple destinations are being used a contour measure can be used, which accumulates the number of possible opportunities that can be reached within a certain travel time or distance. Distant opportunities are considered equally accessible as closer opportunities, as long as these opportunities can be reached within a certain time or distance (Wachs & Kumagai, 1973). Therefore, accessibility levels increase continually depending on the maximum travel limit, which is unrealistic in an actual situation.

Potential accessibility assessments use a more realistic approach to the travel time or distance, by penalizing opportunities further away from the origin. By using a distance decay function that is based on recent empirical evidence within the study area, people's perception of transport can be included in the analyses. Originally presented by Hansen (1959), the gravitational function formed the basis for potential accessibility measures. This function describes the influence of opportunities further away from a zone to be of exponentially less importance, similar to a gravitational force. Different impedance functions are being used in the literature, such as inverse power, negative exponential and Gaussian. Vale & Pereira (2017) describe the course of the different gravitational impedance functions for walking as a transport mode in Figure 2.4. Within this figure, the cumulative-opportunity function can be seen as a rectangular function that considers the travel time to either be acceptable or unacceptable if respectively within or not within a certain threshold.

Competition effects can be incorporated within the analysis to better describe the supply and demand for opportunities at the different locations. Geurs & Ritsema van Eck (2003) distinguish three different categories in modelling competition effects. The first category incorporates the competition effect by evaluating opportunities within reach of an origin, as well as the relevant population within reach from that same origin. Since for many opportunities not only people from the originating zone will be competing, this approach only holds for very small distances between origin and destination. A second approach divides the total supply in a destinating zone by the total number of competitors of that zone. By adding up the results of this relative supply for all zones within reach of the originating zone, the competition effect has been incorporated. A disadvantage of this method is that only a competition effect at the destinating zones is incorporated, which may lead to an overestimation of accessibility. To account for this overestimation, it would be more accurate to incorporate a competition effect from inhabitants of every zone instead of only the destinating zone. This Shen index does not only include inhabitants in the destinating zone, but also incorporates inhabitants in other areas based on the same impedance function that is used in the original function between origin and destination (Pritchard, Tomasiello, et al., 2019). A third and final approach includes two balancing factors in the model. These balancing factors assure that the magnitude of flow (trips in most cases) originating from and destined for each zone equals the correct number for that zone. Using this approach, the competition effect can be estimated thoroughly. This is however an iterative process and therefore the model might have difficulties regarding computing power.

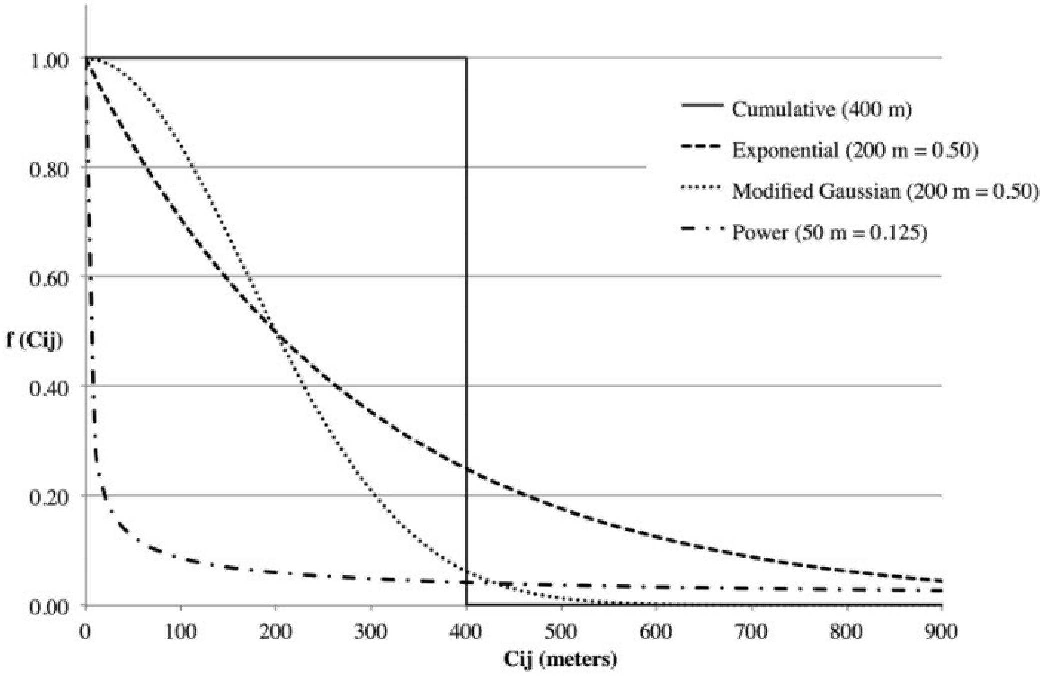


Figure 2.4: Impedance functions to measure accessibility (Vale & Pereira, 2017)

2.3.3 Person-based accessibility

Person-based measures analyse accessibility at an individual level, by determining the activities in which an individual can participate at a certain space in time. Kwan (1998) states that these kind of measures are becoming more and more important in society nowadays, as access to opportunities for individuals of various subgroups has been an important concern. This kind of measure is therefore useful when individual characteristics and constraints need to be accounted for. However due to their demand-oriented nature, these measures do not include capacity constraints of opportunities and therefore competition effects cannot be modelled. Also, the amount of data that is needed to determine the characteristics for every individual is a big disadvantage of these kind of measures.

To determine person-based measures, several restrictions need to be included in the approach to come from a place-based model to a person-based approach (Fransen & Farber, 2019). As seen in Figure 2.5, spatial and network restrictions such as travel time or distribution of opportunities are taken into account in location-based analyses. In order to come from a location-based analysis to a person-based model, individual and temporal restrictions need to be taken into account. These restrictions depict the capability of persons to travel on different times or day, as well as to travel despite their personal circumstances.

A widely used person-based measure can be found in time-space theories, in which a time-geographical approach focuses on keeping track of individuals in time and space (Patterson and Farber, 2015). Main concepts within this approach are potential path areas and activity spaces. Activity spaces can be seen as the locations that a person is bound to in their daily activity pattern. Examples of this are a person's house or job location. Potential path areas on the other hand can be seen as the combination of locations that can be reached whilst travelling between two activity spaces. By determining the potential path area, on must consider the duration that a person resides on an activity space as part of their activity. The potential path area thus reduces in size if the time between two activity spaces decreases.

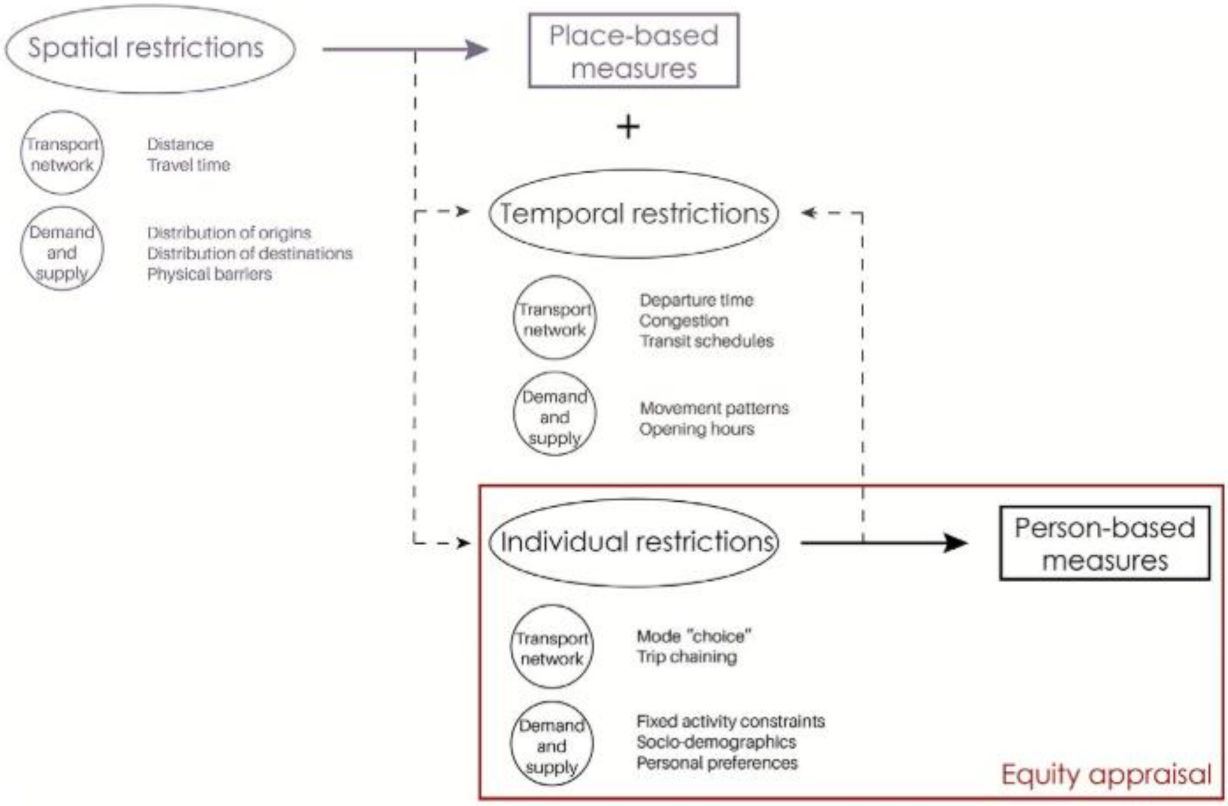


Figure 2.5: From place-based models to person-based models (Fransen & Farber, 2019)

2.3.4 Utility-based accessibility

Utility-based measures evaluate accessibility by using the economic benefits that access to certain activities give. Utility-based measures are efficient due to their capability to define accessibility in terms of economic value, but on the other hand are utility-based measures hard to explain to and interpret by others duo to their complex nature.

One of the most frequently used utility-based methods to determine accessibility is the logsum method. This method determines the provided utility of an alternative by using the log of the denominator of a logit choice probability. One of the advantages of using the logsum method is that heterogeneity in the population can be incorporated, while also incorporating multiple factors that influence choice probability (De Jong et al., 2007). Other sources however state that although in theory any individual component can be incorporated within the logsum method, significant data requirements are necessary to obtain the change in utility for different characteristics (Dixit & Sivakumar, 2020).

2.3.5 Accessibility components using different transport modes

Within a car-free development area, obviously car trips are averted from the area. Instead, other transport modes such as transport by bike or public modes need to replace the demand for car transport. Depending on the travel distance of a trip, different transport modes can be used to replace car transport. For short-distanced trips walking and cycling need to be promoted, whereas for longer distanced trips public transport and car sharing have been proposed to cope with private car trips. Largest differences in accessibility between private car transport and public or shared transport modes is the trip approach. Although from an in-vehicle approach not many differences are noticeable, from a door-to-door approach private car ownership is highly advantageous. The number of steps that need to be taken into account when using a public or shared mode is much larger, especially when making use of a combination of public transport modes. Salonen & Toivonen (2013) illustrate the different steps that need to be made both car transport and public transport in Figure 2.6. Note that when using a shared car, the difference with a private car can be seen in the access distance to the location of the shared car. This is often further away from the residence than a private car and thus increases access walking time significantly. Also, the waiting time before a shared car becomes available, or the time that it takes to order a shared service needs to be considered when using a shared car.

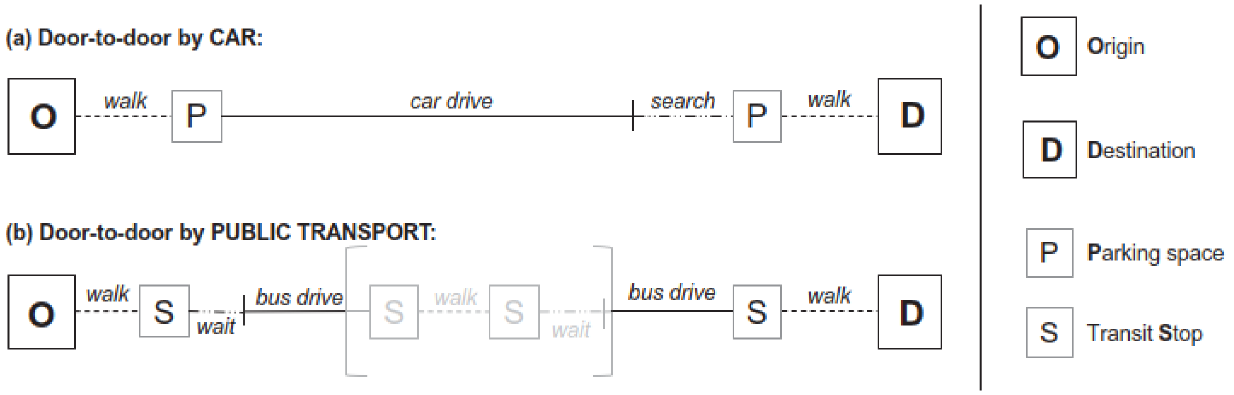


Figure 2.6: Door-to-door apprach for (a) private car transport and (b) public transport (Salonen & Toivonen, 2013)

To minimise the difference in accessibility between private car and public transport usage, integration between public transport or car sharing on the one hand and walking and cycling on the other hand is needed. Three types of indicator measures are key within this integration (Fransen et al., 2015; Lei & Church, 2010).

1. *System accessibility*: Travel time from the origin to the transport station has a large influence on accessibility by public transport modes. This is even more important when taking into account the egress part, as often commuters are unable to use a bicycle for this part and instead are forced to walk the last part of their trip. Within the literature, maximum walking distances to bus stations and rail stations are respectively 400 and 800 meters (El-Geneidy et al., 2014). Maximum allowed distance for cycling as a feeder system depends on the home-based and non-home-based end of the trip, for which Shelat et al. (2018) identified a maximum distance of 3 and 5 kilometre for respectively non-home-based and home-based ends of a trip in the Netherlands.
2. *System facilitated accessibility*: Total travel time or cost that is being facilitated by the transport system itself. The more destinations can be reached by using the public transport system, the higher the total accessibility by public transport when using this mode of transport.
3. *Accessibility provided by service level:* The level of service of the total transport system can relate to multiple aspects. Higher frequencies of the public transport mode will provide more possible departure times throughout a time period. This lowers the average waiting time at the access station, as average waiting time is often perceived as half the headway of vehicles or carriages. Also does a higher frequency reduce the average transit time, as chances are higher that transferring modes depart within proximity of each other (Lei & Church, 2010).

Besides these indicators, aspects that could indirectly influence accessibility can also be distinguished. Providing sufficient bicycle parking facilities reduces the time that travellers need to park their bicycle, whereas also the distance between a bicycle parking and the transit station itself can be minimised. In the Netherlands access to public transport is for most trips already done by means of walking or cycling, with respectively 65 and 25% of all access trips (Martens, 2007). Thus these aspects do not only increase accessibility directly, but also indirectly by promoting the use of cycling towards the transport.

At a national scale, Pritchard et al. (2019) found that bike-and-ride job accessibility is already more than twice as large compared to walk-and-ride job accessibility. In comparison with car transport however, bike-and-ride and walk-and-ride transport modes are nowhere near the amount of accessibility that car transport provides, with accessibility rates of less than 50% and 20% respectively during daytime and night-time as seen in Figure 2.7. At an urban scale however, the difference between car and bike-and-ride accessibility is much smaller. Pritchard et al. (2019) find that in some major Dutch cities bike-and-ride accessibility surpasses the national average car accessibility during peak hours. Nevertheless, car transport on average still provides more accessibility than a combination of cycling and public transport does.

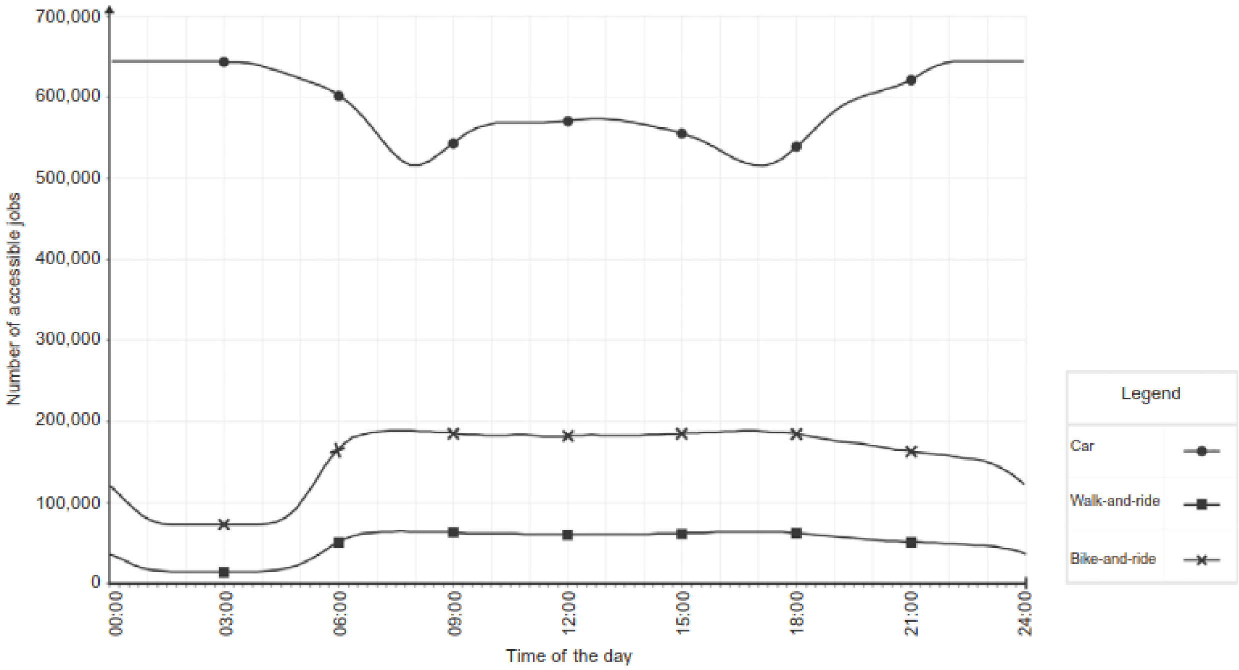


Figure 2.7: Job accessibility with different modes in the Netherlands (Pritchard et al. 2019)

2.3.6 Conclusion on accessibility

Now that the concept of accessibility is evaluated and that accessibility components using different transport modes are distinguished, a conclusion on accessibility is provided. This conclusion provides a summary of the investigated methods to determine accessibility and analyses the suitability to use the different methods and indicators within this research. Table 2-2 provides an overview of the analysed methods to determine accessibility. For each of the methods the indicator to determine accessibility is given, as well as the necessary data and the advantages and disadvantages of every method. Each of the methods is suitable in different circumstances, providing a trade-off between the methods with regard to this research.

As the scope of this research is to find the number of accessible jobs, using an infrastructure-based approach is not useful. Person-based accessibility is also not an option within this research, as a historical set of trips is not available on a disaggregated level. Utility-based accessibility is an interesting approach, making it possible to find relative importance of a single characteristic of a trip. However, as the accessibility model needs to be able to analyse accessibility based on the probability of a trip being made, a utility-based model is only suitable in determining this probability and not in the number of job opportunities. A location-based method appears to best fit the problem within this research. This method is able to combine both the job opportunities in the different destinating areas as the relative probability of a trip being made to these destinations based on the decay functions of the different trip characteristics.

Table 2-2: Overview of analysed methods to determine accessibility

Method	Accessibility indicator	Advantages	Disadvantages	Data type
Infrastructure based	Performance of transport network based on network aspect of the infrastructure itself	Useful when only the impact of the transport network itself is important	Does not account for spatial distribution of activities	Aggregated, based on a number of travellers on a network section
Location based	Number of available opportunities in a destinating zone based on a certain trip characteristic decay function	Different methods that can be used in different situations, undemanding for data	Not every method realistically determines accessibility	Aggregated, based on traffic analysis zones and on a population group level
Person based	The number of opportunities or activities in which an individual can participate with respect to his or her constraints in space and time.	Can depict individual restrictions and capabilities of traveller	Data intensive as a detailed travel diary is necessary to obtain data.	Disaggregated, on an individual level
Utility based	Economic benefit that access to a certain activity provides.	Can depict accessibility in a monetary value.	Complex and difficult to explain to policy makers	Disaggregated on an individual level or aggregated on a population group level.

Within a public transport trip not only in-vehicle time but also waiting time and access time are relevant for the appreciation of a trip. Together, these three trip characteristics comprise the travel time that is expected in a multi-modal trip and determine the likelihood of an individual to make a certain trip. While these three travel time components comprise travel time, cost is also important and therefore in total these four indicators represent public transport accessibility. System accessibility is covered by the access time to the used public transport system, system facilitated accessibility is covered by time being in a public transport vehicle and accessibility provided by the service level is covered by the waiting time at the station. Regarding the accessibility that is provided by the service level, it can be observed that many factors other than waiting time are influential to the service level. Factors like reliability of the waiting time or the capacity of a transport mode could also be influential to the accessibility that is provided by the service level. However, due to the complexity of the choice experiment for the respondents, these characteristics have not been further considered within this research.

3 Methodology

Within this section, the research approach and the need for different methods to obtain answers to the research questions will be explained. First, an introduction to the Merwedekanaalzone as a case study is given. Secondly, the used survey and the choice experiment within this survey will be explained. Finally, obtaining a base scenario for accessibility in Utrecht is presented, after which the accomplishment of the change in accessibility due to the different measurements is described.

To find answers to the different research questions, multiple stages in the methodology can be distinguished. To obtain more knowledge about the Merwedekanaalzone, first the case study is described. Within the case study not only the existing transport network is evaluated, also the various measures that are proposed in and around the Merwedekanaalzone are discussed within the description of the case study. These measures are evaluated in the later described accessibility model to find an answer to research question 3 of the research.

Secondly, the approach of the used survey within this research is described. This survey consists of two separate parts that each find answers to a different sub-question. The first part of the survey is focussed on research question 1 and thus on discovering any differences in the socio-economic characteristics and in the travel pattern between residents in a car-free residential area and a traditional car-oriented neighbourhood. To do so, a revealed preference part within the survey distinguished these characteristics, which in a later stage can be compared to the results of the Mobility Panel Netherlands (MPN) survey (Hoogendoorn-Lanser et al., 2015). The second part of the survey uses a stated preference approach that includes a choice experiment to find the relative importance of the investigated trip characteristics to different population groups. The relative importance of these trip characteristics can be useful when considering research questions 2 and 3, as they are used in the established accessibility model that evaluates job accessibility in the Merwedekanaalzone.

A final methodological explanation is given on the used accessibility model within this research. In combination with the results of the stated choice experiment, this model analyses job accessibility in multiple scenarios in the Merwedekanaalzone. The output of this model is used to answer research question 2 and 3, as respectively a base scenario as the effect of various measures can be analysed using this accessibility model.

3.1 Case study

Now that car-free development as well as changes in car ownership have been studied, the used car-free development area within this research can be analysed. The Merwedekanaalzone is a car-free development area, located within the urban area of Utrecht, the Netherlands. As the project area is located closely to the city centre and the central station of Utrecht, accessibility is already high for different modes including cycling and public transport.

3.1.1 Focus of municipality

The Merwedekanaalzone is a newly realised neighbourhood, consisting of three different areas. As seen in Figure 3.1, the neighbourhood is bound by the Merwedekanaal on the eastern side and the Europalaan/Overste Den Oudenlaan on the western side. The A12 highway on the southside and the Doctor M.A. Tellegenlaan define the area, while multiple traversing streets split the neighbourhood into the three areas. Whereas in all sub areas plans are present to reside new inhabitants, only in sub area 5 plans are present to utilise the area as being car-free development. Within sub-area 5 specifically, 5000 to 6000 new residences with a very high density will be built. This area has been designed following a limited access model, with restricted access for motorised vehicles and a parking place ratio of 0.3 is present. By limiting the number of parking places in the neighbourhood, more spatial area is available to provide a sustainable and liveable neighbourhood that is mainly focused on walking and cycling.

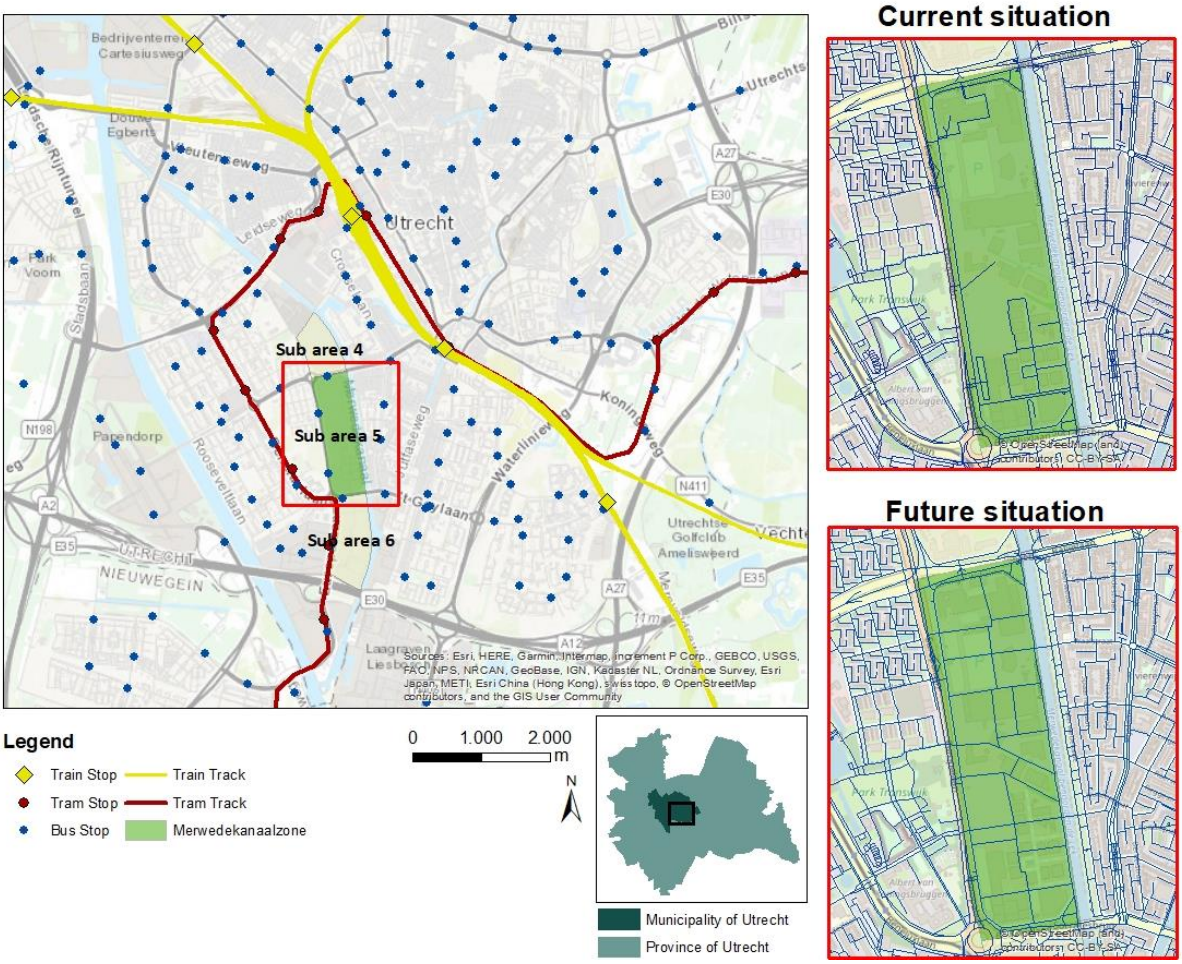


Figure 3.1: Overview of the Merwedekanaalzone and its surrounding transport features

While walking and cycling are suitable for short-distanced trips, they can however not replace car transport for longer-distanced trips. To achieve a car-free situation in which residents can preserve their original amount of mobility and accessibility, the municipality of Utrecht strives for several main pillars to be fulfilled (Gemeente Utrecht, 2018).

1. A spatial design that is focussed on walking, cycling and public transport. This spatial design needs to be flexible spatial design that can be altered if necessary, depending on the progress of car-free development in the Merwedekanaalzone.
2. Different networks for different transport modes that fit car-free development, in which differentiated accessibility for different transport modes is present. Dynamic traffic management should be present to manage different transport flows and provide sufficient accessibility with all transport modes.
3. Newly built mobility HUB's that stimulate the used of shared transport in the Merwedekanaalzone, as well as an ambitious parking strategy for private cars and bicycles.

3.1.2 Proposed measures

If the Merwedekanaalzone is realised without any extra measures, guaranteeing a liveable and accessible neighbourhood is not possible. Therefore, several measures have been proposed in the Merwedekanaalzone, both by the municipality as well as by experts from Mott MacDonald. By implementing these measures, it is attempted to guarantee mobility for all inhabitants, regardless of their travel distance or travel preferences. The different measures can be found itemised beneath, together with the consideration whether they will be used within the analysis (Gemeente Utrecht, 2018). Figure 3.2 provides an overview of the measures that experts from both the municipality and Mott MacDonald have proposed. Differences in measure between the municipality and Mott MacDonald are only noticeable in the proposed tram network, which will be discussed at the according section.

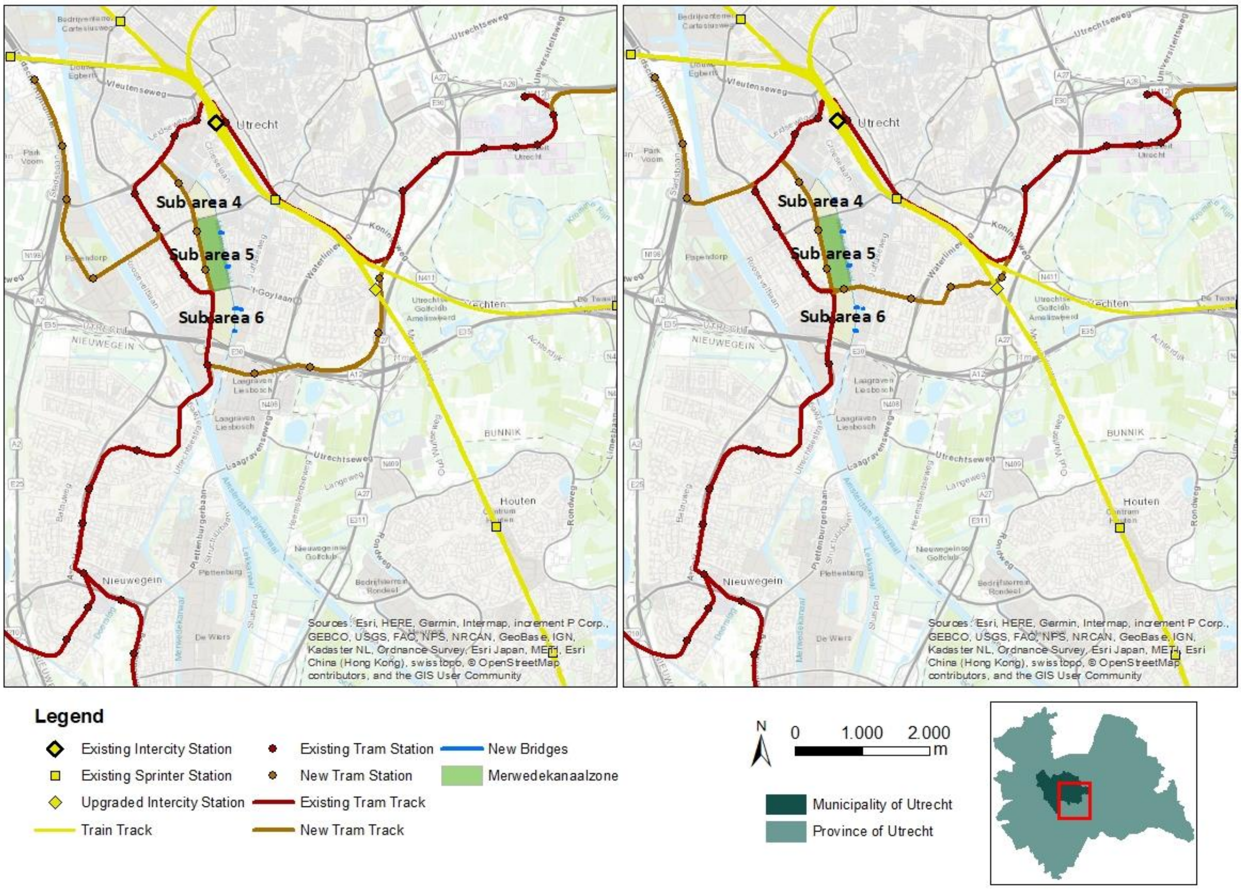


Figure 3.2 (a) **Figure 3.2 (b)**

Figure 3.2: Overview of proposed measures by the municipality (a) and Mott MacDonald (b) in the Merwedekanaalzone

a. Walking: Increase possible travel range of inhabitants in southwest Utrecht.

As the Merwede channel acts as a natural barrier both from the Merwedekanaalzone to opposing areas as vice versa, the total area that inhabitants can travel to by foot is limited. This gives an isolated effect for both areas and prevents the two areas from interacting with each other. Residents of the Rivierenwijk cannot make use of transport facilities, while residents of the Merwedekanaalzone cannot make use of commercial facilities in the Rivierenwijk and quick access to train station Vaartsche Rijn. By constructing two bridges that stretch over the Merwede channel in the study area, these areas become more accessible and both areas can benefit from shops and services in their counterpart. Altogether, the walkable travel range increases significantly by realising this measure (Goudappel Coffeng, 2019). Possibly also longer distance accessibility increases, as these bridges provide a quick connection to several train stations. Therefore, this measure will be considered within the accessibility analysis of this research. An analysis on the best possible location for the different bridges, not only regarding the mobility aspect, has already been finished. Within the study area, planned locations for bridges are the Waalstraat and Zijldiepstraat. Within sub area 4 and 6, bridges are planned at the Heycopstraat and Karperstraat respectively.

b. Cycling: Improving cycling network with separated cycling lanes for quick access to the centre of Utrecht

A key problem within Utrecht is the number of cyclists that make use of a single cycling lane. Especially during peak hours, cycling lanes are congested with a mix of traditional bikes and fast-paced e-bikes or mopeds. The increase in traffic volume gives an increased risk of bike-bike collisions, but also decreases the average travel speed of cyclists on the route. In a former stage the cycling network in Utrecht could be seen as a fishbone structure, in which several supplying lanes led to a main cycling lane that connected the different neighbourhood. To spread to total volume of cyclists, the municipality has defined several routes that will be upgraded to better spread the cyclists. Thus, in the future situation multiple main cycling lanes will be present that all connect different neighbourhoods with each other. Some of these routes will also traverse the newly presented bridges, thus destined for both cyclists as persons on foot. As the bike is commonly used by commuters in Utrecht, as well as providing a first- or last-mile solution for commuters that use public transport, this measure will be considered within the analysis.

c. Public transport: New rapid-transit line next to the Merwedekanaalzone

Public transport in Utrecht is in the current situation mostly focused on Utrecht CS, with major train, tram and bus connections being present at this location. Changes in the tram network are on the first place considered to reduce the travel time to Utrecht CS. Currently the SUNIJ tram line is present in Utrecht, connecting Utrecht CS to Nieuwegein and IJsselstein and adjoining the Merwedekanaalzone along sub area 6. A second line connects Utrecht CS to Utrecht Science Park, with plans being made to connect both lines and form a single tram line from Utrecht Science Park to Nieuwegein and IJsselstein. To reduce travel times on this tram line, measures have been proposed to extend this line with an extra line: the Merwedelijn. This will cause the tram line to be complete adjacent to the Merwedekanaalzone, following the Europalaan until the end of sub area 4.

A third line is proposed perpendicular to the proposed Waterlinielijn, connecting the Europaplein to Utrecht Science Park via train station Utrecht Lunetten. This track focusses on destressing Utrecht CS and instead guides passengers via Utrecht Lunetten. As no detailed suggestions on the track have been made, two different tracks have been considered by both the Municipality as Mott MacDonald. One of these track is located directly within the neighbourhood of Lunetten, while the other track is located more towards the south and follows the A12 highway.

Besides changes in the tram network, an upgrade of train station Utrecht Lunetten is considered by the municipality. This upgrade makes it possible for intercity trains to also stop at this station, besides the already stopping sprinter trains. An extra platform is planned that makes it able for trains from Arnhem to stop at this station, while still being able to serve trains that come from the direction of ‘s Hertogenbosch. As both measures not only reduce the travel time to Utrecht CS but also reduce the access time of residents in the Merwedekanaalzone, both measures are likely to influence accessibility and thus need to be considered within the analysis.

d. Shared transport modes: Multiple hubs that facilitate different forms of shared transport

Since there are no parking spots adjacent to houses and streets available within the Merwedekanaalzone, car transport is limited within the area. Instead, the municipality strives for an increase in shared transport modes that replace regular car transport. The distribution of these transport vehicles will be done via mobility hubs and parking garages, which have been proposed at several locations in the Merwedekanaalzone. Multiple smaller hubs are favoured over one large hub, as they better suit the built environment and give small access times for different inhabitants. Each hub will have a combination of services that can be used by the residents. A digital environment will make users capable of ordering their shared transport vehicle, dependent on their individual needs and preferences. A physical mobility shop is also present, consisting of a service desk, rental of special vehicles and a bike repair shop. Finally, the mobility hub facilitates delivery goods that cannot be delivered to the residences directly, making it possible for the inhabitants to pick up their goods if they have the time to do so. Including this measure within a network-based analysis is difficult however, as a shared car is making use of the same infrastructure as a private car does. Therefore, using a shared car is not considered within the later described analysis.

e. Retain private car: Park and ride at municipal boundaries

Although it is not desired, it is possible that the number of individual cars exceeds the possible number of parking spots within the direct surrounding of the Merwedekanaalzone. One of the solutions that has been suggested by the municipality is using the park and ride facilities at the municipal boundaries of Utrecht, close to the main highways. This makes it possible for inhabitants to maintain the possession of their individual vehicle, while still keeping the Merwedekanaalzone to be a car-free area. A (shared) bicycle or public transport connection can then be utilised to get from the park and ride to the residence in the Merwedekanaalzone. As a measure, the municipality has designated 700 parking spots at a park and ride location for inhabitants of the Merwedekanaalzone. These designated parking spots are a temporary solution, gradually lowering the number of reserved parking places within the park and ride location. Eventually, when individual car ownership reduces to a minimal number, the municipality fully diminishes the available parking spots and only relies on other transport modes to ensure accessibility for inhabitants. Therefore, as this is only a temporal solution, this measure will not be considered within the analysis.

3.2 Choice modelling

Often in survey results, large differences are present between what respondents say they would do compared to what they actually do. Respondents are generally incapable of determining the reasoning behind their travel pattern, as there are possible many factors influencing this travel pattern which could be unknown to the respondent itself. Within survey experiments, two different kind of methods are therefore present to determine preferences of transport users. *Revealed preference techniques* try to analyse the actual travel behaviour of respondents. Nowadays this is mostly done by making use of a travel diary in which historical trips of respondents are being collected and analysed. This is a very precise method, resulting in the actual preference of respondents that can be found throughout a certain span of time. It however also requires the respondent to capture their location throughout this period or requires the respondents to remember every trip that has been made when collecting the trips afterwards. Both practical (time consuming, expensive, unavailability of data) as well as methodological (collinearity and variability of variables, model assumptions) disadvantages of revealed preference methods have been extensively described by Louviere et al. (2000).

As a result, *stated preference techniques* are being used to determine travel behaviour and preferences without the need of actual trips to be collected. Instead, hypothetical trips are being proposed to the respondent in order for the characteristics to be analysed. Ideally, there would be no difference between the observed and stated preferences of respondents. However, in practice respondents are not always capable to correspond their stated preferences with their actual preferences (Wardman, 1988). Nevertheless, stated choice experiments are often used in transportation studies for estimating behaviour of transport users, as prior to implementation the effectivity of a characteristic can be evaluated.

Within this research a combination of revealed preference and stated preference methods is necessary. For the first stage of the analysis the revealed preference of the inhabitants is important, to see the differences between a traditional neighbourhood and a car-free neighbourhood. As the project area is still undeveloped and thus no trips from and to the Merwedekanaalzone have been made, for the second stage of the analysis only a stated preference research method is applicable. To do so, an understandable and intuitive choice experiment needs to be constructed, in which the different aspects are considered that potentially determine the choice of respondents to live in a car-free residential area. Within the remainder of this section this experiment as well as the determination of the influence of the characteristics is discussed.

3.2.1 Discrete choice experiment

In discrete choice studies, the independent influence of different variables is determined by letting the respondents complete a number of choices in which they select one of the described options from a set of alternatives. This stated choice technique, also known as discrete choice modelling, gives the possibility to explore a large set of characteristics that vary in scale. Within discrete choice modelling, various concepts play an important role. To get a better understanding of the different concepts, Train (2003) describes these concepts thoroughly:

- Attributes depict the different possibilities that are present within an alternative. These attributes remain the same throughout the survey. Attribute values on the other hand are being altered during the survey, giving the respondents the possibility to vary their decisions based on these values.
- Alternatives depict the combination of attributes and attribute values that a respondent can choose from, within this research in the form of different car-free development areas. These alternatives need to be mutually exclusive from the respondent's perspective, as choosing one alternative directly implies not choosing any of the other alternatives. Secondly, the set of alternatives needs to be exhaustive. By adding an extra alternative in which the decision-maker decides picking none of the alternatives, the choice set is guaranteed to be exhaustive. Thus, appropriate definitions of the different alternatives are necessary.
- The choice set can be seen as the set of alternatives, where the decision-maker can choose from. A full factorial choice set consists of all possible alternatives, however very often the amount of available time limits the possibility to carry out a full factorial design. Therefore the use of a fractional factorial design is necessary.

In order to generate an experimental design that produces statistically reliable parameter estimates for the different attributes, several design types need to be considered. In an ideal situation, a full fractional design would be included within the design. This gives the possibility to estimate both main effects as interaction effects, best describing the utility of the different attributes (Rose & Bliemer, 2009). Due to practical reasons however, the number of alternatives in a full factorial design is often not feasible. Therefore, in most cases it is necessary to make use of a fractional factorial design. This design reduces the number of alternatives that are present within the choice set, which can be done in many different ways. Largely implemented fractional factorial design is the so-called orthogonal design. This design aims to minimize the correlation between the different attribute levels that are present in the design, thus ensuring that the attributes are statistically independent. This gives the possibility to determine the independent influence upon the observed choices. Orthogonality does however not provide any information about whether the respondents relate two characteristics with each other psychologically, such as price and quality of a product (Rose & Bliemer, 2009). Instead, orthogonality is only a statistical suitability indicator of the design of the experiment.

Mostly due to the ease of which a design can be constructed and the relation with linear models, in which orthogonality plays an important role, an orthogonal design has traditionally been the most common design type. However, whereas orthogonality plays an important role in determining independent effects in the linear models, discrete choice models are not orthogonal (Train, 2003). Discrete choice models instead follow a typical S-shaped curve, to account for the high change in probability when utilities of different alternatives are situated on similar levels. Therefore, over the past years efficient designs have emerged in the literature. Instead of looking at the correlation between the attribute levels, an efficient design tries to find designs that are statistically as efficient as possible in terms of predicted standard errors of the parameter estimates. To do so, attribute level combinations should be chosen in such a way that as a result the smallest possible parameter covariances are present (Willumsen & Ortúzar, 2011).

Two different approaches are present in designing an efficient design. Whereas the one creates design under the null hypothesis having zero values coefficient priors, the other design is created under the assumption that non-zero values coefficient priors (Willumsen & Ortúzar, 2011). Within the latter approach a decision needs to be made on the values of these coefficient priors, which causes more effort but constructs a more efficient design. The statistical efficiency of experimental design can be evaluated either by the D-efficiency, which minimises the generalised variance of the model output, or the A-efficiency, which minimised the variances of the parameter estimates (Louviere et al., 2008). D-efficiency is mostly used as it is easier and faster for a computer program to optimize this efficiency. Also, the ratio of two D-efficiencies for two competing designs is invariant under different coding schemes. This gives the possibility to compare different designs, which is not possible for A-efficiency (Kuhfeld, 2010). D-efficiency of 100 indicates a completely orthogonal design, while a D-efficiency of over 90 is often considered to be appropriate.

3.2.2 Determining the Multinomial Logit Model

Among the discrete choice models, a multinomial logit (MNL) model is widely used within different applications as it is easily interpretable (Train, 2003). This model tries to find the consideration between a set of mutually exclusive alternatives (Aloulou, 2018). Individual preferences or perception of aspects can be considered as the selection process between the different alternatives. Depending on these preferences an individual will value one aspect of a car-free development area over another, resulting in an objective function that the individual tries to optimise. This objective function reflects the rational behaviour of the individual, thus also being different for every individual. By using a multinomial logit model, the estimated probability of a certain alternative according to the given aspects can be determined. Considering that every individual has a different objective function that depends on the set of existing characteristics, presence or absence of certain aspects will result in a different level of utility that the choice of the alternative gives to an individual. Taking in mind that the objective function is random, the function can be broken down into a deterministic part and a random, resulting in the following expression:

$$U_{iq} = V_{iq} + \varepsilon_{iq} \qquad (1)$$

Where, U_{iq} is the level of utility that an alternative *i* gives to an individual *q;*

V_{iq} is the deterministic or representative utility, reflecting the perception of an average individual of the satisfaction provided by the choice characteristics of the alternative *i*;

ε_{iq} is the random function, reflecting the non-observed behaviour of the individual.

The deterministic part of this probability function can be formulated as a function that consists of the explained variables within the mode. Equation (2) can be used to determine the utility of an alternative. It is possible that for a certain alternative *j,* X_{jkq} is set to 1 for all *q.* By doing so, the utility parameter β_k is used as an alternative-specific constant (ASC) for alternative *j* (Louviere et al., 2000). At most (*J* – 1) ASCs can be specified within a multinomial logit model, as otherwise a perfectly collinear set of measures would be the result. If however a variable X_{jk} is present within every representative utility function for all alternatives, the utility parameter β_{jk} can be seen as generic and can be replaced by β_k as this terms is similar for all alternatives. To estimate the utility parameters within equation (2), the researchers can provide an initial guess for the utility parameter, which are used as a starting value in the utility function. Prior knowledge is however needed to determine this initial value, thus instead also iterative procedures are used to find better values of β until a certain level tolerance is reached.

$$V_{jq} = \sum_{k=1}^{K} \beta_{jk} X_{jkq} \tag{2}$$

Where, V_{ij} is the level of utility that alternative *j* provides to individual *q*;

X_{jkq} are explanatory variables, characterising the environment of the attributes;

β_{jk} is the utility parameter, reflecting the weight of each explanatory variable X_{jkq}.

As two individuals that have the same observed characteristics can make different choices, the error term ε_{ij} is incorporated within the function. If the error terms are independent and identically distributed, referred to as Gumbel or type 1 extreme value distribution, the density for each unobserved component of utility and the cumulative distribution can respectively be characterised in the form of equation (3) and (4). Independency within this context indicates that the error for one alternative does not provide information about the error of another alternative. The specified variables explain a sufficient amount of utility, in order for the error term to be uncorrelated and only consist of noise.

$$f(\varepsilon_{iq}) = e^{-\varepsilon_{iq}} e^{-e^{-\varepsilon_{iq}}} \tag{3}$$

$$F(\varepsilon_{iq}) = e^{-e^{-\varepsilon_{iq}}} \tag{4}$$

By using the provided equations for the unobserved terms of the probability and considering independency and identical distributions, equation (5) can be seen as logit choice probability of a single alternative. The logit probability of a single alternative lies between zero and one, and the choice probabilities for all alternatives obviously sum to one.

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

Within this choice probability function, a number of assumptions need to be evaluated. First of all, the Independence from Irrelevant Alternatives (IIA) is considered within this model. IIA states that the ratio of the probabilities of choosing one alternative over another is unaffected by the presence of any additional alternatives in the choice set (Louviere et al., 2000). This, as an advantage, gives the opportunity to introduce or eliminate alternatives without the need of re-estimation of parameters. On the other hand, attributes of utility may not be independent of each other, leading to biased parameter and errors in the estimation of utility. Secondly, the probability that an alternative is being picked by a respondent should be positively signed, assuring that there is always some utility present in every alternative. Thirdly, irrelevance of the alternative set effect is assumed. This states that it is not possible to distinguish a different alternative that can be considered but is not within the choice set, thus that there is finite set of alternatives that a respondent needs to pick from.

Estimating the parameters of the MNL model can be done using maximum likelihood estimation (Louviere et al., 2000). Maximising equation (6) with respect to the utility parameters β is an iterative process, possibly requiring an initial guess for the utility parameters. The iterative procedure is often continued until a certain level of tolerance is reached, after which optimal values for each β has been found.

$$L^* = \sum_{q=1}^{Q}\sum_{j=1}^{J} f_{jq} \ln P_{jq} \tag{6}$$

Where, L^* is the log likelihood function that should be maximised;

f_{jq} is a dummy variable that is either 1 if alternative *j* is chosen and 0 otherwise;

P_{jq} is the probability function of the various alternatives;

3.2.3 Variations to the Multinomial Logit model: Latent Class Logit models

As described in the previous sections, one of the basic assumptions is the independency of the error term throughout the different observations. This assumption holds when every respondent within the analysis is making a single choice decision based on their preferences. In a discrete choice experiment as used within this research however, individuals are making multiple decisions based on their individual preferences. As these decisions are based on the same decision process of the individual, the error terms are therefore not independent anymore and the assumption is violated. This introduces the need of other models that focus on relaxing the strong assumptions with independent and identically distributed error terms (Louviere et al., 2000).

A different variation to the Multinomial Logit Model can be used when the different alternatives are not systematically different, but taste heterogeneity is assumed to be present among respondents. The Latent Class Logit (LCL) Model in Equation (7) provides similar results in comparison to the Multinomial Logit model, however finding results for different identified classes (s) in the data (Shen, 2009). The LCL model assumes that a discrete number of these classes are sufficient to represent the preference heterogeneity across classes, distinguishing the respondents based on unobserved variables. A large difference between the LCL model and the wider known Mixed Logit models is that the former specifies classes using a discrete distribution, while the latter uses a continuous approach to find heterogeneity between individuals (Hess, 2014).

These classes do not contain specific responses or a set of responses from a single respondent, hence being called latent. Instead, specific parameters, including socio-economic parameters, can be included in the model generation. The combination of these parameters gives a specific chance of a respondent belonging to a certain class. Therefore, socio-economic parameters can be included within the model, similar to the extent to which alternative specific parameters can be included in a multinomial logit model in case of dependent response indicators. Note that these socio-economic parameters itself do not account for the difference in taste, but instead underlying non-observed variables that each of these socio-economic parameters represent cause the heterogeneity between respondents.

$$P_{(iq|s)} = \frac{e^{V_{iqs}}}{\sum_{j=1}^{J} e^{V_{jqs}}} \tag{7}$$

3.2.4 Output of Multinomial Logit Model and Latent Class Logit Model

After determining the structure of the MNL and LCL model itself, the quality of the model can be determined by evaluating different aspects (Louviere et al., 2000). First of all, the estimated utility parameters β can be evaluated, in which it is determined whether the parameters are significantly different from zero.

Asymptotic standard errors for the utility parameters are used to test the statistical significance of individual utility parameters using an asymptotic t-test.

To determine whether the model fits the set of data sufficiently, several goodness-of-fit tests are present. When any nonlinearities or interaction effects could be missed within the model, the sum of squares of the smoothed residuals can be used. Smoothed residuals are a weighted average of the residual itself and the other residuals which are close to it in covariate space (Goeman & Le Cessie, 2006). Strongly correlated residuals that are close to each other will not significantly change the residuals, while if no correlation is present the residuals will diminish to zero.

The ρ-squared or likelihood-ratio index shows the explanatory power of the utility attributes of the model, similar to R^2 in ordinary regression (Louviere et al., 2000). The ρ-squared value (Equation (8)) is always between 0 and 1, whereas values between 0.2 and 0.4 can be considered to be sufficient. If the ρ-squared value is adjusted for the degrees of freedom, the adjusted ρ-squared can be determined. The adjusted ρ-squared (Equation (9)) takes into account the number of used variables in the model and thus determines the effectiveness of adding an extra variable in the model.

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

$$\bar{\rho}^2 = 1 - \frac{L^*(\hat{\beta}) / \sum_{q=1}^{Q} \left(J_q - 1\right) - K}{L^*(0) / \sum_{q=1}^{Q} \left(J_q - 1\right)} \tag{9}$$

Where, K is the total number of variables X_k in the model;

J_q are the number of faced alternatives;

$L^*(\hat{\beta})$ is the maximised value of the log likelihood function L^*;

$L^*(0)$ is the value for the log likelihood function L^* such that the probability of choosing an alternative is equal to the observed aggregate share in the sample of the alternative.

When the maximum likelihood estimation method is being used to determine the utility parameters within the mode, a likelihood ratio test is a good determinant for the goodness-of-fit. Within this test, the null hypothesis that is being tested states that the probability of an individual choosing an alternative is independent of the value of the parameters (Louviere et al., 2000). If this hypothesis holds, the utility parameters can be considered to be zero. As this hypothesis of independence is almost always rejected, this test is mostly used to determine whether subsets of the utility parameters are significant and can be used to test nested logit models.

Another method to assess the quality of especially a LCL model is minimising the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC) in Equations (10) and (11) (Hensher et al., 2003; Louviere et al., 2000; Shen, 2009). These criteria are especially useful when the number of classes is unknown and can thus be considered using these criteria. The difference between AIC and BIC is related to the number of parameters (*K*) in the model (Profillidis & Botzoris, 2019). When both criteria evaluate a similar model, the BIC provides larger penalties in case of increased parameters compared to the AIC.

$$AIC = -2\left(L^*\left(\hat{\beta}\right) - S * K_\beta - (S-1)K_\gamma\right) \tag{10}$$

$$BIC = K_\gamma * \ln(S) - 2L^*(\hat{\beta}) \tag{11}$$

Where, $L^*(\hat{\beta})$ is the maximised value of the log likelihood function at the estimated parameters;

K_β is the number of elements in the utility function of the class specific choice model;

K_γ *i*s the total number of parameters in the model;

S is the number of classes that are selected within the model.

3.3 Survey design

By making use of the described approach of the following section, the survey that is used in this research is designed. The complete survey can be found both originally in Dutch (Appendix A) and translated in English (Appendix B). First, the survey outline will be presented, after which specifically the discrete choice experiment will be discussed.

3.3.1 Survey outline

Within the survey the respondents follow a specific path to complete the survey. Different question groups can be distinguished within this path, while also depending on the given answers a different survey path will be followed. A graphical representation of the survey groups and paths can be found in Appendix C.

The following parts can be distinguished within the survey:

1. **Introduction**: The respondent will be asked about their plans of relocating within the upcoming 3 years and about their interest in living in a car-free neighbourhood. This will be used to do analyses while accounting for attitude towards car-free living. Occupation of the respondent will be used in the introduction to determine the path on trip characteristics.
2. **Trip characteristics**: If the respondent is employed, travel mode and time to their job location will be asked. Also satisfaction of the mode and time are useful to know, as this indicates whether their preferred travel time and mode differs from their actual travel time and mode. If the respondent in unemployed, their most frequent trip and trip purpose will be questioned to determine these trip characteristics.
3. **Transport modes**: Usage and presence of transport modes gives the possibility to find whether transport modes are being used when the particular mode is available or whether available transport modes are not being used at all. Attitude towards the different transport modes can explain this potential gap between available transport modes and used transport modes.
4. **Car ownership**: Number of owned cars and incentive to own a car can be compared to the national average to see whether residential self-selection will take place in a car-free neighbourhood. As on-street parking is discouraged or prohibited in most car-free residential area, other parking preferences in and around car-free neighbourhoods need to also be compared.
5. **Capabilities**: Being able to differentiate between different capabilities gives the possibility to find accessibility for groups that are less mobile, that are not able to use a certain transport mode or that are technologically disadvantaged.
6. **Discrete choice experiment**: The discrete choice experiment will be defined in-depth in the next section. Concisely, the respondent will have to choose between two car-free neighbourhoods that differ in transport system aspects, while also indicating whether they would give up car ownership for one or multiple vehicles in the selected neighbourhood.
7. **Socio-economic**: Finally, socioeconomic characteristics will provide a better distinguishment of population groups, together with the capability section. Also, socioeconomic characteristics of the

population in a car-free residential area can be compared with national averages to see whether residential self-selection is taking place.

3.3.2 Choice experiment design

To obtain a discrete choice design that properly depicts the utility of the respondents, the concept of accessibility that has been discussed in Section 2.3.5 will be used. This concept states that accessibility by public transport is different from normal car transport in terms of access and egress time, while also the time waiting on the public transport station needs to be taken into account. Therefore not only travel costs and travel time are important, as waiting time and access time could be considered to be less comfortable than the time actually being in the public transport mode (Van Hagen, 2011).

As a result, four different attributes have been considered that are being altered throughout the choice set, which can be found itemized below. Due to complexity and efficiency of the choice set, within every attribute three different attribute levels have been used. All attributes contribute to providing accessibility from a location within the car-free development area and are therefore useful in the later described accessibility analysis. Within all attributes, the attribute level giving the lowest expected utility is considered as a reference level in comparison to the other attribute values. Table 3-1 provides an overview of the attribute levels in the discrete choice experiment.

1. In vehicle travel time of trip: The difference in time that a person is actually within the public transport mode itself, compared to the original travel time to their job location or frequently visited location.
2. Access time to nearest public transport station: Time that it takes for a person to walk to the nearest public transport station.
3. Average waiting time before departure at public transport or shared car station: Time between arrival at the public transport station or shared car location and departure.
4. Usage cost of a shared car for a fixed distance and time: As in one-way trips using a shared car is not an option due to the absence of handing in the vehicle, a large renting time for a predefined cost have been used within the analysis. Costs are an average of car sharing operators in the Netherlands (Claasen, 2020).

Table 3-1: Attributes and attribute values used in discrete choice experiment

Attribute	Level	Description
In vehicle travel time	0	20% faster than current tip
	1	Same as current trip
	2	20% slower than current trip
Access time to station	0	6 minutes walking
	1	12 minutes walking
	2	18 minutes walking
Average waiting time	0	Average waiting before departing is time 5 minutes
	1	Average waiting before departing is time 10 minutes
	2	Average waiting before departing is time 15 minutes
Costs shared car	0	€15 for renting 5h and traveling 50km
	1	€25 for renting 5h and traveling 50km
	2	€35 for renting 5h and traveling 50km

The number of different choice sets that need to be filled in by respondents cannot be too large, as this will increase the chance of respondents quitting the survey or clicking through the survey without making a thorough consideration between alternatives. Therefore, a maximum of five choice sets will be given to the respondents. In order for the design to be sufficiently efficient, respondents will be evenly spread among five different choice designs. This results in a total of 25 different choice sets in which the alternatives are considered. A choice set has been generated by making use of a pilot version to eliminate redundant choices that would be advantageous for one alternative in all attribute values. The full choice set can be found in Appendix D. As a fractional factorial design has been used for the choice set, efficiency of the design needs to be evaluated. By using the presented choice design, a D-efficiency of 95 is reached, indicating that the choice design is not orthogonal but is appropriate to use.

3.3.3 Survey respondents

To determine commuting trip characteristics and to evaluate the relative importance, respondents need to be collected that complete the described survey. As the described project area, the Merwedekanaalzone, is not fully developed yet, similar car-free or low-car development areas have been used to collect respondents. Five potential areas have been considered to be useful within this research, of which only the areas in *italic* were applicable to find respondents in.

- *Merwedekanaalzone*: A total of 1100 residences are already realised within the planned car-free neighbourhood that is discussed in Section 3.1. Residents in the neighbourhood have been invited to complete the survey through door-to-door flyers.
- Cartesiusdriehoek: A car-free development area planned on an old train yard of NS in Utrecht. As no residences have been realised yet within this area, only interested persons that signed up for an online newsletter can be approached to fill in the survey.
- Beurskwartier: Similar to the Cartesiusdriehoek, located in Utrecht. Most notable difference is the extremely short distance to Utrecht Centraal, providing excellent connections using public transport.
- *GWL Terrein*: A sustainable and car-free neighbourhood in Amsterdam, with over 600 households. With parking facilities only at the edges of the area, a car ownership ratio of barely 0.3 per household is achieved. Distribution of the survey both through flyers and an online newsletter can potentially be used within this area.
- *Ebbingekwartier*: A neighbourhood in Groningen with approximately 500 households, in which cars have limited access to the area. To discourage car ownership within the neighbourhood, parking permits within the local parking garage bring additional costs.

The answers to this survey can be used to construct a general model that represents the value that inhabitants in a car-free development area give to certain trip characteristics. This general model can thereafter be used to evaluate accessibility in a case specific situation in the Merwedekanaalzone.

3.4 Modelling accessibility

When modelling accessibility, a GIS network needs to be created to facilitate trips from origin to destination. Within this transport network, multiple layers are present that each characterise one of the transport modes that could potentially be used to facilitate a trip. Figure 3.3 illustrates the steps that are necessary to obtain total accessibility. In the rest of this section the different steps are described more in-depth.

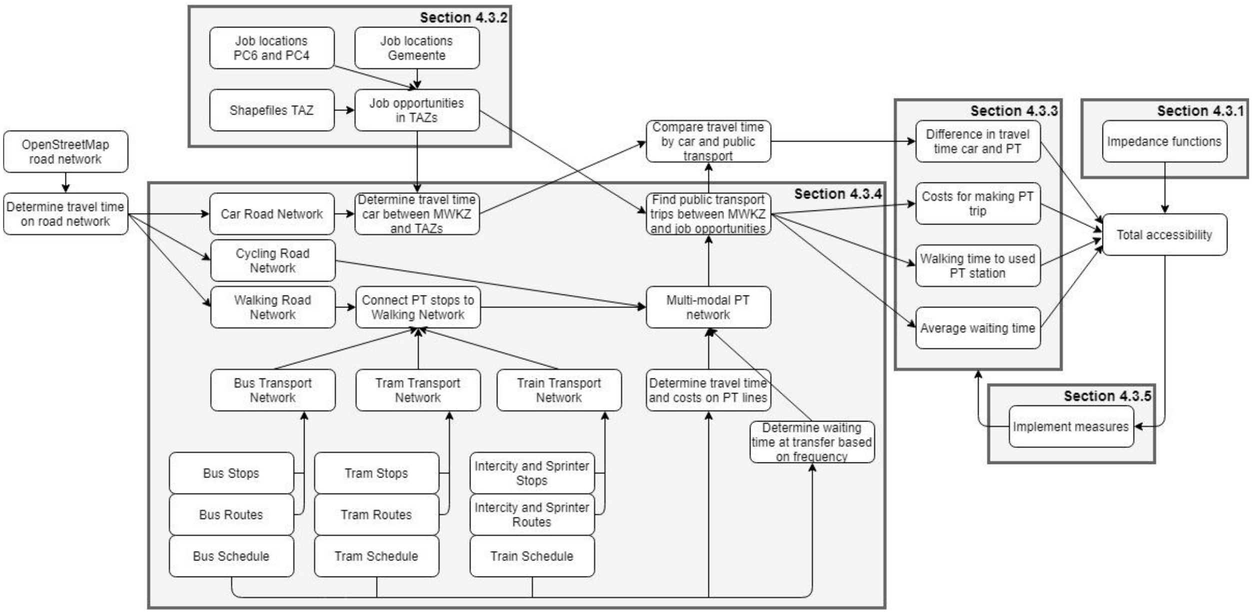


Figure 3.3: Used GIS approach to model accessibility

3.4.1 Impedance function

While most of these impedance functions are based on a single cost such as travel distance or travel time, within this research multiple factors will be considered to have an effect on accessibility. Therefore, an impedance function that includes a combination of these characteristics need to be studied. Within their studies Cascetta et al. (2013, 2016) try to determine accessibility by making use of the expected value of the maximum perceived utility, as seen in Equation (12). By making use of a probability impedance function it is not only possible to include the availability of a trip (space-time component), but also to include the level of utility that the trip provides to a particular individual (behavioural component). It is possible to determine the probability $p_{i,d,s,t}$ of a certain trip being made within Equation (12) by expressing it using a logit model. Equations (13) and (14) depict the influence of competitors to the evaluation of accessibility. Within the first equation, a competition effect is only incorporated by including the population in the destinating zone. In the latter equation however, a more sophisticated competition effect based on the Shen Index (Pritchard, Tomasiello, et al., 2019) is incorporated by including the population in every zone that compete based on a decay function. Equation (15) depicts this probability, both for inhabitants from the origin zone as for inhabitants that compete, based on the level of utility that the trip gives. This probability is dependent on both socio-economic attributes of the population group that determine the value of a trip characteristic, as well as on the trip characteristics of the transportation system between origin and destination.

$$A_{i,s} = \sum_{d=1}^{D} K_d * p_{i,d,s,t} \tag{12}$$

$$K_d = \frac{O_d}{P_d} \tag{13}$$

$$K_d = \frac{O_d}{\sum_i P_i * p_{i,d,s,t}} \quad (14)$$

$$p_{i,d,s,t} = e^{(\sum_t \beta_{s,t} X_{i,d,t})} \quad (15)$$

Where, $A_{i,s}$ is the provided accessibility in origin *i* for population group *s;*

K_d are the number of available activities such as number of jobs or schools at destinations *d.*

O_d are the total number of job opportunities in destination *d*

P are the total number of inhabitants in either the origins *i* or in the destinations *d*

$p_{i,d,s}$ is the probability that the trip between origin *i* and destination *d* is being made by an individual from population group *s,* dependent on the trip characteristics *t*

$\beta_{s,t}$ is the relative increase or decrease in utility of a certain trip characteristic *t* in population group *s*

$X_{i,d,t}$ is the actual value of trip characteristic *t* within a trip between origin *i* and destination *d*

To determine this impedance function, a consideration on the scale of the parameters need to be made. Within the discrete choice experiment a categorical parameter scale is used, as this makes it possible to determine the utility coefficient for the different attribute values. In the accessibility analysis however, a probability impedance function that contains continuous parameters is preferred. This gives the opportunity to determine the provided utility for every possible trip between an origin and a destination, defining accessibility more precisely. The discrepancy between the two requires a conversion from categorical to continuous utility parameters, for which a function needs to be fit through the utility coefficient that are used in the discrete choice experiment.

As a hypothesis, it can be expected that an increase of travel characteristics will have a negative influence on the probability of making a certain trip. The magnitude of this influence will however differ based on the relative costs that an individual gives to a characteristic. As a rule of thumb, Hossain et al. (2015) state that out-of-vehicle time in the form of walking and waiting time are considered to be twice as inconvenient in contrast to in-vehicle time. Wardman (2001) however declares that this inconvenience is only 60% higher for walking and waiting, compared to in-vehicle time. According to Hossain et al. (2015), walking time turned out to have a nonlinear relation with the amount of provided utility. Whereas the level of provided utility decreases relatively quick when small waking distances need to be overcome, this reduction is less notable for additional distances over 150 meters. In the same study, similar nonlinear statements apply for waiting times at a station, as they state that waiting times over 5 minutes are relatively less inconvenient per minute of waiting compared to waiting times of under 5 minutes.

Regarding the exact valuation of walking and waiting time compared to in-vehicle time, different conventions are present in the literature. In their multi modal transport model, Gunn et al. (1985) find evidence that disutility of walking time and waiting time is higher compared to in-vehicle time. For walking and waiting, a disutility of respectively 2.4 and 1.8 times the disutility that in-vehicle time provides. Other modelling studies state that in comparison to in-vehicle time, walking time (1.5 to 2.0 times in-vehicle time) is better appreciated than waiting time (1.5 to 2.5 times in-vehicle time (Department for Transport London, 2014; Wardman, 2004). The provided literature thus only provides minimal conclusions on the relative valuation between walking and waiting time. As a hypothesis, it can therefore be alleged that both walking and waiting time are considered to be providing more disutility compared to in-vehicle time, but it is unsure which of the two is providing the most disutility.

3.4.2 Traffic analysis zones

After a probability decay function has been generated that considers the different trip characteristics, accessibility of jobs in different traffic analysis zones (TAZ) can be evaluated. Trips from the Merwedekanaalzone to these zones in the Netherlands are generated using either car transport or a combination of walking or cycling and public transportation. As destinations close to the Merwedekanaalzone will be of larger influence on the accessibility, accessibility needs to be determined on a smaller scale compared to locations further away from the project area. Therefore, three different scale tiers have been constructed. The first scale comprises the municipality of Utrecht, in which all PC6 areas have been considered to be an area. The second scale contains the province of Utrecht, excluding the municipality of Utrecht, in which PC4 areas are considered as a zone. For destinations outside the province of Utrecht, being the other provinces of the Netherlands, municipal boundary areas cover the possible set for which accessibility need to be evaluated. An overview of these locations can be found in Figure 3.4

Figure 3.4: Accessibility areas as used in the analysis

The number of jobs need to be determined in every analysis zone, to find the total accessibility provided within the study area. As the areas differ in scale, the number of jobs need to be collected via different methods. The difficulty to obtain the number of jobs is higher in small areas, as the location of the jobs needs to be determined more precisely.

For jobs close to the study area, being considered by the boundaries of PC4 and PC6 areas, specific locations of the jobs have been used as input. These locations are publicly available through the Provinciaal Arbeidsplaatsen Register (PAR, *Provincial Job Register*) (Provincie Utrecht, 2020). Company locations as well as the number of jobs per company have been summarised over the PC4 and PC6 areas for respectively the province and municipality of Utrecht. For jobs outside the provincial boundaries of Utrecht, municipal employment opportunities have been considered (LISA, 2020).

An overview of the number of jobs per area can be found in Figure 3.5. At a national scale it can be noticed that the number of jobs is high in municipalities surrounding the province of Utrecht, while more rural locations within the periphery of the Netherlands provide less job opportunities. Within the province of Utrecht an increased number of jobs can be found at the southern edge of the municipality, in which the cities of Nieuwegein, IJsselstein and Houten are located. Other notable cities that contain many job opportunities are Amersfoort, Zeist and Veenendaal in the eastern and north-eastern parts of the province. On a municipal level, areas that provide a significant number of opportunities are the Papendorp business park in the southern part of the city, the industrial harbour area in the northern part of the city and the medical centre and science park on the eastern side of the city.

If, as seen in Figure 3.6, an internal competition effect in the destinating area is included within the analysis, it can be noticed that differences are flattened out on a municipal level. On a local level however, as seen in Utrecht itself, disparity between residential areas and commercial or industrial areas are strongly visible in the number of jobs per inhabitant. This becomes evident by the low number of inhabitants in commercial areas, as well as the low number of job opportunities in residential areas. A third approach is depicted in Figure 3.7, showing the number of available job opportunities in an area when an external competition effect is incorporated. Within this competition effect, the Shen Index as referred to in Equation (14) is used, thus also taking into account competition from inhabitants in other zones than the destinating area. As seen in the figure areas outside of the major cities in the Randstad suffer from the good connections towards their location, resulting in an increase in competition. More remote areas in the Netherlands suffer less, due to both worse connections as well as the number of inhabitants. Within Utrecht itself, less disparity is present. Areas that contain a large number of job opportunities still provide more available jobs per competitor, although being less noticeable compared to only internal competition.

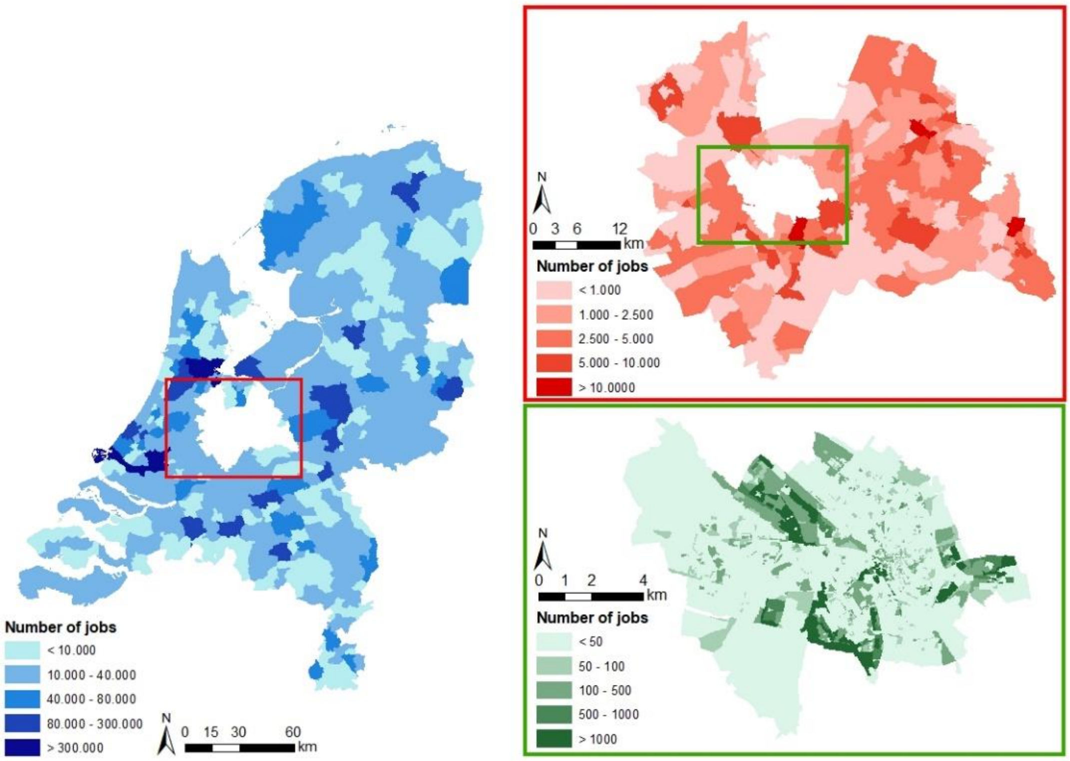


Figure 3.5: Jobs in different municipalities in the Netherlands (blue), different PC4 areas in the province of Utrecht (red) and in different PC6 areas in the municipality of Utrecht (green).

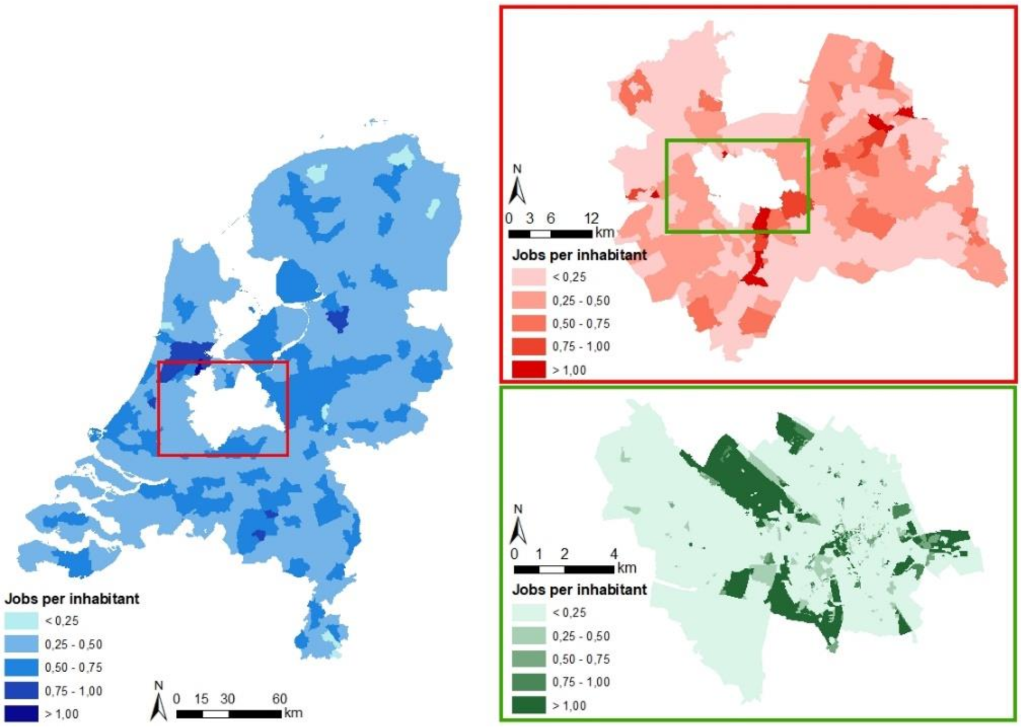


Figure 3.6: Jobs per inhabitant in municipalities in the Netherlands (blue), different PC4 areas in the province of Utrecht (red) and in different PC6 areas in the municipality of Utrecht (green).

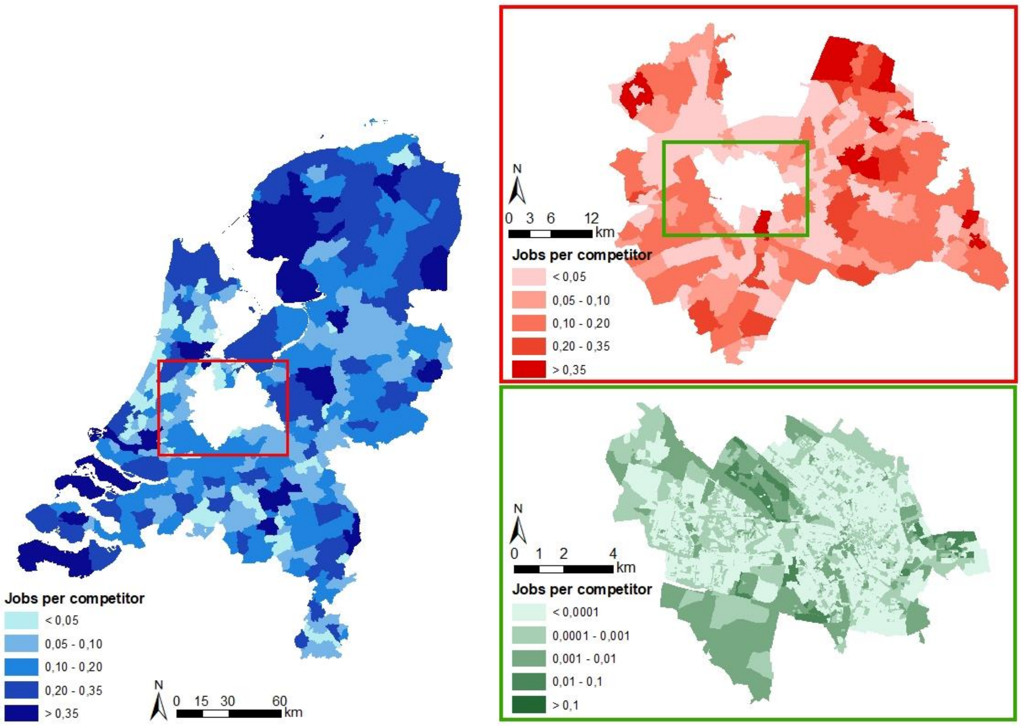


Figure 3.7: Jobs per competitor (Shen Index) in municipalities in the Netherlands (blue), PC4 areas in the province of Utrecht (red) and in PC6 areas in the municipality of Utrecht (green).

3.4.3 Modelling trip attributes

Travel costs: Depending on the type of public transport and the distance covered in that transport mode, costs will be different. Differences can be noticed either in the fixed costs for boarding the transport mode or for the variable costs for the distance travelled within the transport mode. Table 3-2 shows the fixed and variable costs per kilometre travelled (NS, 2020; U-OV, 2020). Note that variable train costs are not representing actual distance but rather a relative distance, as NS tries to provide comparable costs from station A to B via two nearly similar trajectories.

Table 3-2: Fixed and variable costs for public transport (NS, 2020; U-OV, 2020)

Cost Attribute	Bus	Tram	Train
Fixed boarding cost	€ 0.98	€ 0.98	€ 0.00*
Variable costs per km	€ 0.169	€ 0.169	€ 0.30

**If total travel distance is under 8 kilometres, a travel cost of €2.40 is considered*

Travel time: Within the discrete choice experiment travel time has been modelled in terms of percentage of the original trip duration. Trips could either be 20 percent longer or shorter, or have an equal travel time. To relate to this in the analysis, trips by car transport are used as the original trip duration while the same trip made by public transport are used to depict a car-free situation. The difference between the two is then used to determine the relative increase or decrease in travel time by public transport.

Walking time to public transit station: Walking costs are modelled as a decreased utility per minute of extra walking time to the transit station within the discrete choice experiment. By using the walking network, the distance to the used public transport station is determined. Taking an average walking speed of 5 km/h results in the walking time that is needed to reach the transport station.

Waiting time at transit station: Waiting time is modelled as a decreased utility per minute of extra waiting time at the transit station in the utility. The average waiting time at a transit station can be seen as half the headway of schedule. This is however only true if passengers have a random arrival process at the station and are thus unaware of specific departure times of vehicles, which is only the case if headways are very small. However if frequencies decrease and headways thus increase, it is possible that passengers will anticipate their arrival time on the station on the departure of the transport mode. This results in a density function for the waiting time that is skewed towards a lower waiting time compared to half the headway.

Ingvardson et al. (2018) provide an overview of the cumulative distribution function and the normalised waiting time for different headways in Figure 3.8, considering that the timetable is published. As expected, the higher the headway of a public transport service, the higher the possibility that an individual adapts his arrival time on the station on the departure time of the transport mode. These functions can be used to determine the average arrival time at the station, as well as the average waiting time at the station before departure of the transport mode. Table 3-3 provides the average waiting time for the different frequencies, deducted from the cumulative distribution functions in Ingvardson et al. (2018). These waiting times are used to model a transfer from the walking network to the public transport mode that is used to make a trip.

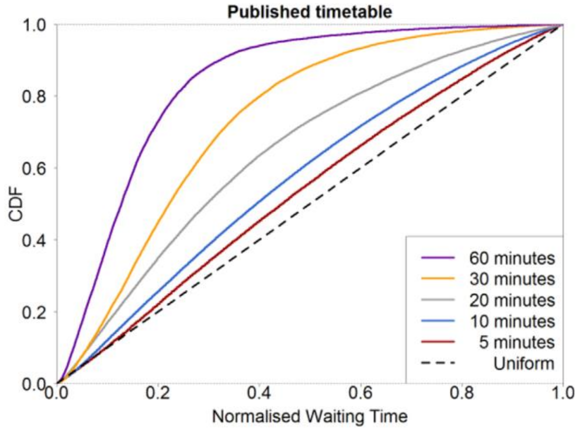


Figure 3.8: Waiting time distributions for different service headways, when timetables are available (Ingvardson et al. (2018))

Frequency (Trains per hour)	Headway (Min)	Average waiting time (Min)
1	60	9.9
2	30	7.9
4	15	5.6
6	10	4.3
12	5	2.3

Table 3-3: Average waiting time for different headways in public transport (Ingvardson et al. (2018))

3.4.4 Modelling transport network in Geographic Information System

After obtaining the destinating zones and the trip attributes, the total transport network can be realised. Several layers are necessary to obtain this network, which will be discussed in the remainder of this section.

First, data from OpenStreetMap (OSM) is used to determine streets suitable for car transport. For a large part of the network, maximum allowed speeds are already defined. For road sections that have an unknown speed limit, the type of road is used to approximate the speed limit. This results in a network in which road section lengths and speed limits are present. To account for congestion, traffic lights and other nuisances, it is assumed that the average speed on a particular road is 90% of the maximum allowed speed. The travel time from the Merwedekanaalzone to the other areas by car transport is obtained by using the travel distances and average speed on the route.

Secondly, a layer is created for the different forms of public transport, being bus, tram and train transport. Public transport lines represent the network, on which the earlier determined trip attributes are projected. Public transport stations are positioned on the transport lines, which form the connection between the layers. To create the possibility to include transfer time in case of an intramodal transfer, different bus lines and different train services have been given a virtual location close to the actual service. To illustrate this solution, Figure 3.9 provides an example of a bus stop where multiple bus lines connect. As seen in the figure, every bus line received a virtual location based on their respective bus line number. Every virtual bus stop is connected to the projected bus stop located on the street network. This ensures that transfer time can be included in case of a change from one bus line to another, while also ensuring that passengers can enter a bus line at the designated bus stop.

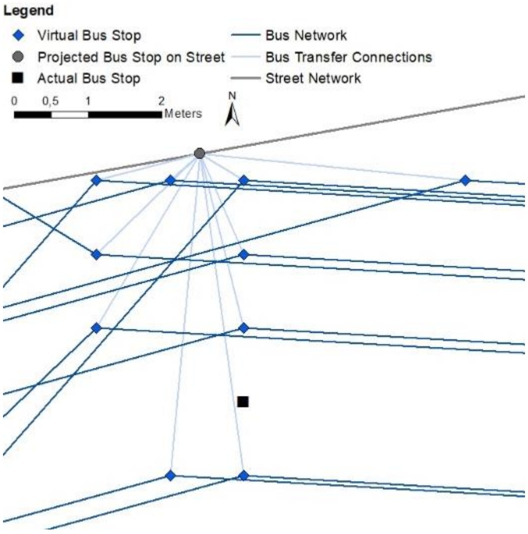


Figure 3.9: Virtual shift at transport stations to ensure a correct way of modelling transfers

Thirdly, OSM data is used to create a layer of walkable streets in the province of Utrecht. This layer is cleaned and travel time on all road sections are determined by assuming an average walking speed of 5 km/h. Public transport stations and job opportunity locations in the province of Utrecht are connected to the walking network to assure that destinations are reachable on foot. For job locations outside the province of Utrecht, which are represented by municipal boundaries, reachability is assured by connecting the zone to the closest train station. A fixed travel time per kilometre is used to represent the distance that travellers need to overcome from their destinating train station to their job location.

Fourth, connectivity between the different transport modes and thus the different layers is modelled. As all the layers are connected to the walking layer, this layer is used to facilitate not only the first access transfer but also the transfers from one public transport mode to another. Costs of going from one layer to another layer can be seen as access waiting time or transfer waiting time. Costs of leaving a transport mode are neglected, as no waiting time is present when leaving a transport mode. An overview of the layers and the connectivity between the layers can be found in Figure 3.10. As seen in the figure, it is not possible to directly transfer from one public transport mode to another. Instead a traveller needs to first return to the walking network, thus including the access cost of entering the public transport network another time.

Finally, the trip attributes on the network are implemented within the network. These trip attributes are used in the accessibility model to find the shortest path with the highest chance for an individual to make this commuting trip. To account for the expected utility that each of the trip characteristics provide, waiting time and walking time are rated differently within this analysis. As it is assumed from the literature study that out-of-vehicle time is perceived twice as negative compared to in-vehicle time, walking time and waiting time will also be given twice the penalty that in-vehicle time provides.

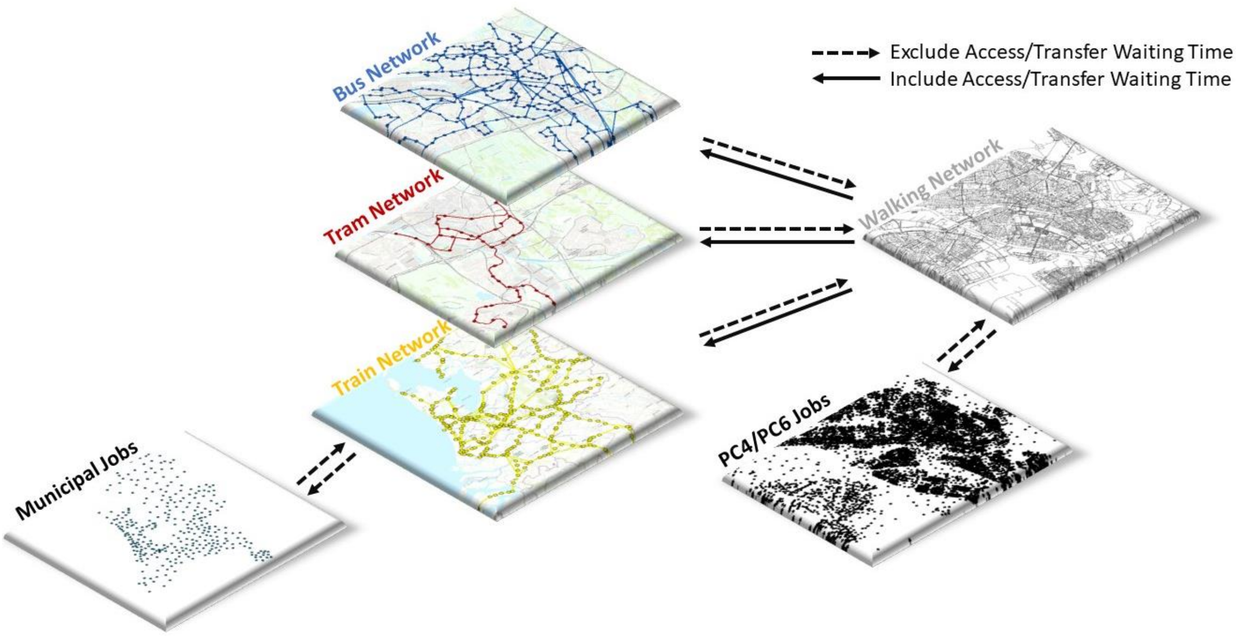


Figure 3.10: Connectivity of the different layers in the GIS network

3.4.5 Implementing measures in the network

After a base scenario is constructed and characteristics of multi-modal trips can be extracted from the model, measures that have been proposed to be implemented in the area can be modelled within the network. Figure 3.11 once again illustrates the different measures that have been proposed in the Merwedekanaalzone as described in Section 3.1.2.

- Within the layer that represent walkable and cyclable streets, the proposed street layout of the area has been drawn. Bridges over the Merwedekanaal have been implemented in the same layer, making it possible for travellers to cross the channel on several location in the project area as well as other sub-areas in the Merwedekanaalzone.
- To illustrate the implementation of new rapid transit lines within Utrecht, routes have been added within the light rail layer or existing light rail routes have been redrawn. In case of knowledge about headways, travel times and costs these have been added for particular routes. When these characteristics are unknown, it is assumed that these characteristics are similar to the already existing light rail routes in Utrecht.
- Besides the realisation of a new light rail route through Utrecht, one of the measures assumes train sprinter station Lunetten to be transformed to a new intercity station with platforms on both the rail lines Utrecht – 's Hertogenbosch and Utrecht – Arnhem. This makes it easier for travellers to access neighbourhoods in the southern parts of Utrecht, potentially decreases travel time to large parts of the city. Especially in combination with a new light rail route that connects the Merwedekanaalzone with this station, this measure can have a large influence on accessibility from the Merwedekanaalzone.

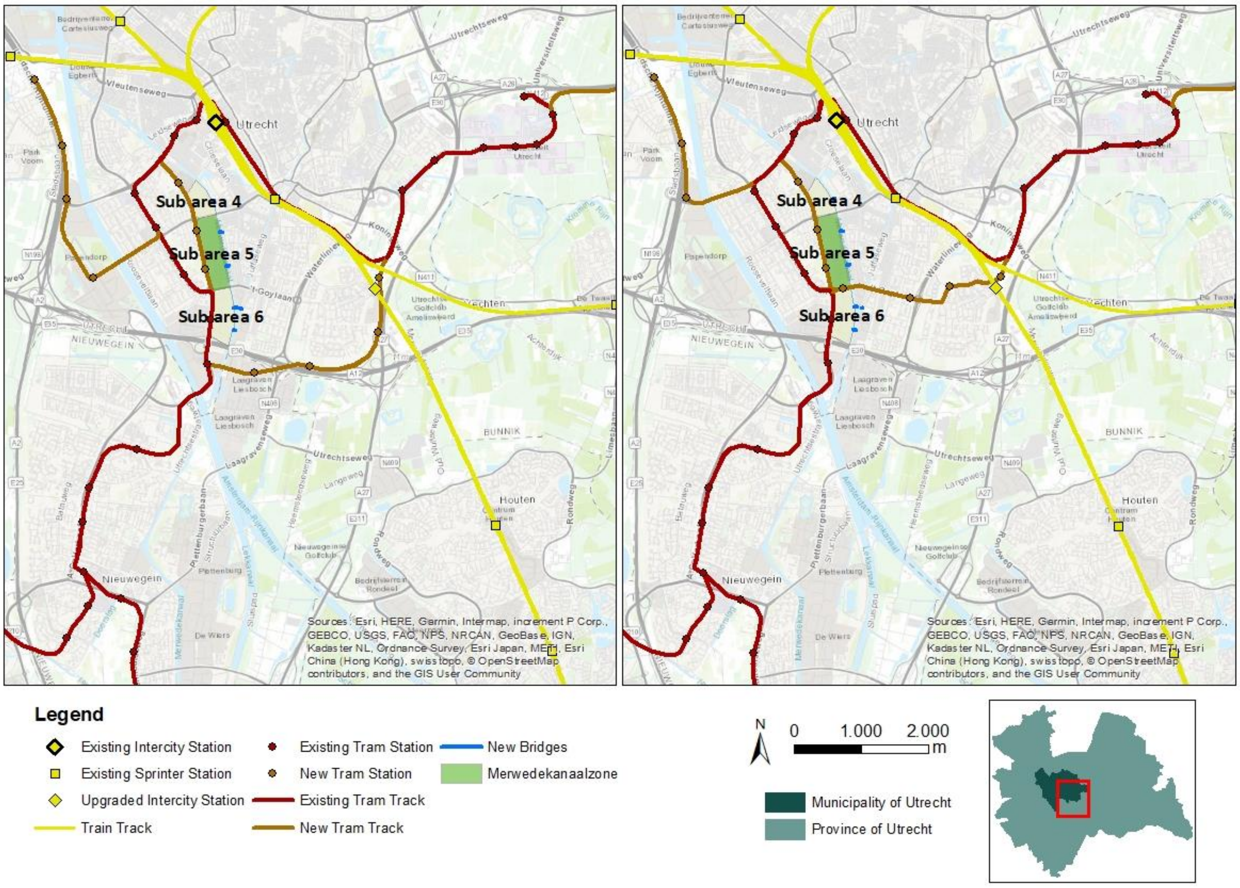


Figure 3.11 (a) **Figure 3.11 (b)**

Figure 3.11: Overview of proposed measures by the municipality (a) and Mott MacDonald (b) in the Merwedekanaalzone

4 Data analysis

Within this chapter the survey output will be discussed and compared to a nationwide average as collected by the Mobility Panel Netherlands (MPN) Survey. First the survey response will be evaluated. Secondly the survey statistics will be analysed both on a socio-economic level as on a transportation level. Finally, the trip characteristics will be evaluated and the estimated model will be discussed

4.1 Survey response

For the three areas in which respondents have been collected, as discussed in Section 3.3.3, an overview of the responses can be found in Table 4-1. As seen in the table, most responses (42%) have been collected in the GWL Terrein, followed by the Ebbingekwartier (34%) and the Merwedekanaalzone (24%). As not all respondents finished the entire survey, the number of useful responses turned out to be lower. With an average total response rate of almost 9%, and a 7,5% of useful response rate, the expected number of 10% response rate has not been reached. This is mostly due to the lack of available opportunities to spread the survey online in different areas.

Table 4-1: Summary of collected responses

	Total	Merwedekanaalzone	GWL Terrein		Ebbingekwartier
Response type		Flyer	Flyer	Newsletter	Flyer
Distributed flyers	2300	1200	600	-	500
Total Responses	204	48	65	22	69
Responded Percentage	8.9%	4.0%	10.8%	-	13.8%
Useful Responses	170	43	51	16	60
Useful Percentage	7.4%	3.6%	8.5%	-	12%

4.2 Descriptive statistics

This section particularly focuses on the statistics regarding socio-economic and transportation, which summarize the collected responses in this research. Exact results of the data in the figures can be found in Appendix F. The collected statistics are compared to a nationwide average that has been collected in research done by KiM (Kennisinstituut voor Mobiliteitsbeleid), which is falling under the Ministry of Infrastructure and Water Management (Hoogendoorn-Lanser et al., 2015). This Mobility Panel Netherlands (MPN) Survey is held on a yearly basis, collecting travel patterns on an individual as well as on a household level. After this section, the first research questions can be answered:

1. How do individuals that opt on living in a car-free neighbourhood differ from an average household in the Netherlands?

4.2.1 Socio-economic

Working situation - On an occupation and income level, notable differences can be distinguished in Figure 4.1 within the financial situation between the collected responses and the MPN respondents. Residents in a car-free development area are more often (self-)employed and on average have a higher yearly income per household compared to respondents of the MPN survey. This indicates that living car-free is easier to accomplish for higher income households, due to either relatively high transport costs when living car-free or due to the relatively high prices of the residences in these areas. Another possibility however is that the distribution of income within the category ‘unknown’ is not evenly distributed between the two samples, as low-income household are less likely to answer this question due to being ashamed by their financial situation.

Given the fact that within the sample a large number of high-income households are present, it is possible that this can be noticed within the trip characteristic evaluation of this group. When income levels increase, relative costs of making use of the transport network decrease. This could lead to a situation in which an increase in travel costs does not lead to a change in the utility level that a transport trip provides. In Chapter 5, more results regarding this topic will be given.

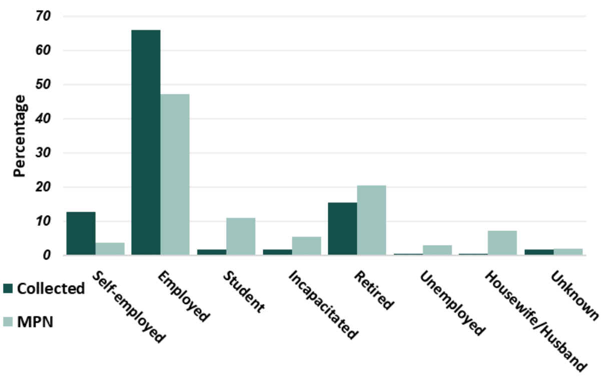


Figure 4.1 (a)

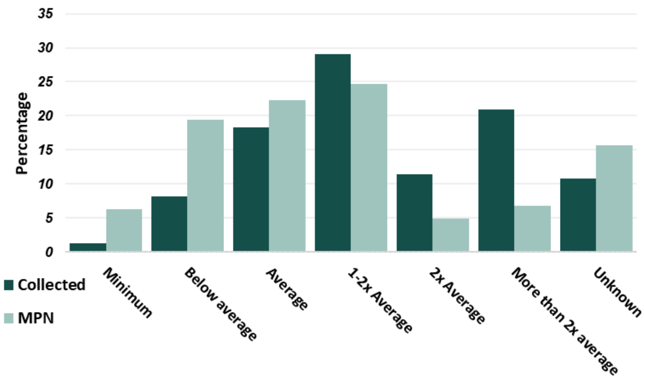


Figure 4.1 (b)

Figure 4.1: Occupation (a) and income level (b) of survey respondents and MPN respondents

Age – Looking at the relatively high income levels in the survey sample, together with the employment rate of this sample, it is expected that age of the respondents represents their employment rate. This expectation is confirmed in Figure 4.2, showing that persons of over 60 years of age are less present within car-free development areas. Instead, household with residents between 30 and 40, or between 50 and 60 years old are more often present within the sample.

A possible explanation for the low number of senior adults in the sample is that these persons are more constrained by habitual patterns compared to younger persons. Therefore, it could be more difficult for these older-aged people to give up car ownership and live in a car-free residential area. Also, as the observed neighbourhoods have been realised recently, the fact that senior adults relocate less often could cause the underrepresentation of this population group. However, due to senior adults being less likely to give their age it is possible that a large group of respondents in the category ‘unknown’ belongs to a high age group. Therefore, results should be cautiously interpreted when comparing the survey sample to the respondents of the MPN.

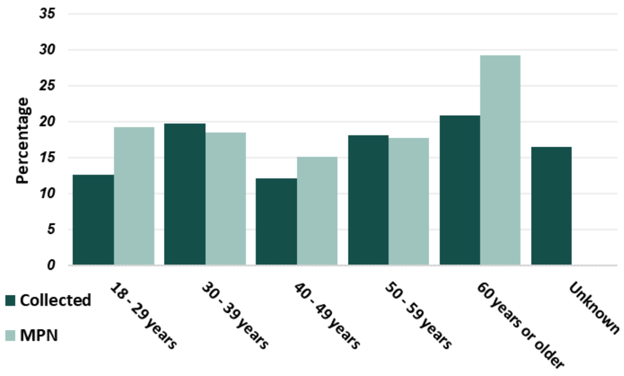


Figure 4.2: Age of survey respondents and MPN respondents

Household composition - Within the household compositions in the two samples, Figure 4.3 shows that families are slightly less likely to live car-free. Both single-parent families as well as couples with children are less present in the collected sample, suggesting that it is difficult for family household to live in a car-free neighbourhood. Possibly, the increase in visited locations in case of children being present in a household cause this difficulty (Clark, Chatterjee, et al., 2016). The absence of children in the sample is in line with the age distribution. This results in households that either have no children yet, or in households in which children have already moved out. Within the number of persons per household this deficiency in children can also be noticed, as 2-person households can be identified more regularly. Surprisingly, when children are present, households in car-free development often contain two children. This in contrast to families with either one or more than two children, which are less present within the collected sample.

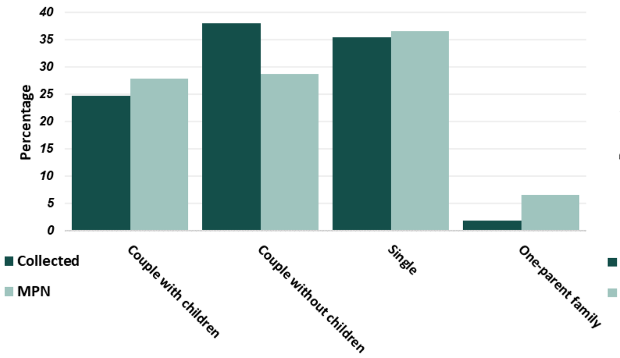


Figure 4.3 (a)

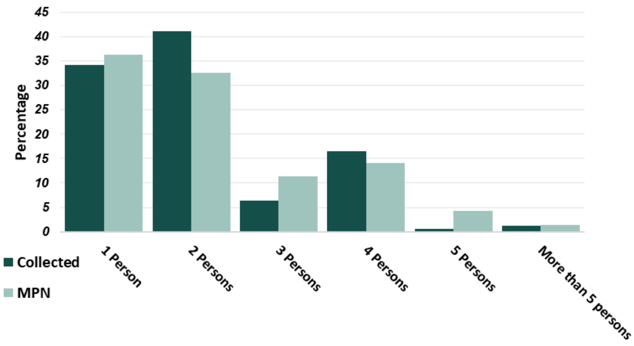
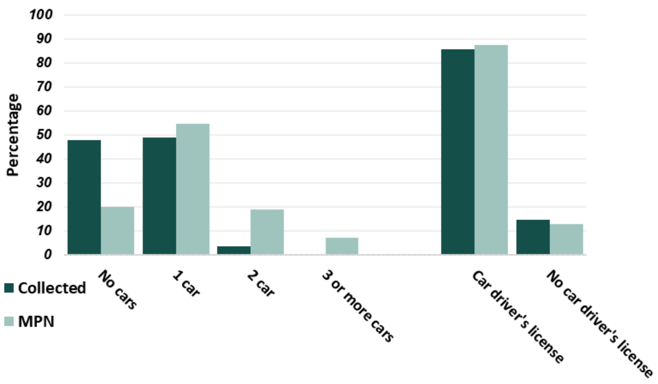


Figure 4.3 (b)

Figure 4.3: Household composition (a) and number of persons in a household (b) of survey respondents and MPN respondents

***Car ownership* -** Within the investigated areas car ownership is, not surprisingly, very different from the average Dutch sample. As most of the areas in which surveys have been collected are low-car and not completely car-free, almost half of the households still own one or more cars. It can be noticed however, that the number of households that own more than one car is minimal. This implies that households that live in a car-free neighbourhood in almost every situation opt to dispose car ownership partially. Looking at the share in driver's license, while also taking into account the high-income levels in the sample, this car ownership reduction is not due to their capacities or financial situation but instead indicates that the respondents deliberately choose not to own a car or to own less cars.

Looking at the different reasons to own a car, it can be noticed that most of the respondents state that they own a car due to the mobility that it provides compared to other transport modes. Fewer respondents, but nevertheless a significant number, state that rather their destinations are better accessible using a private car. Thus, it can be observed that both the mobility aspect of public transport as well as the accessibility impact are perceived worse compared to private car usage by the respondents that own a car. Moreover, the feeling of freedom or control when using a private car is frequently mentioned by respondents. This is in line with the reduction in cars from multiple cars to one car, indicating that at least one car is necessary in many households to be used in occasional situations.



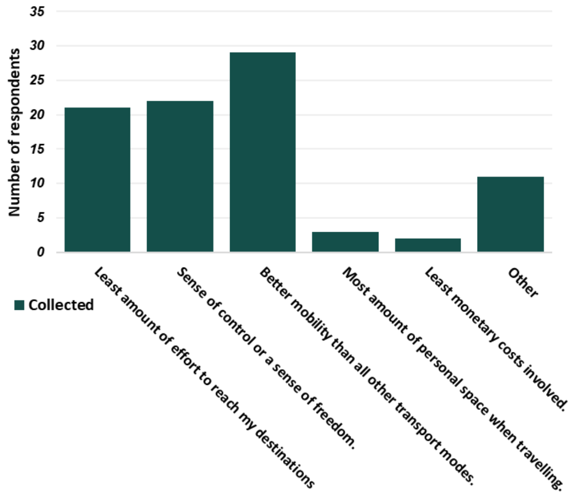


Figure 4.4 (a) **Figure 4.4 (b)**

Figure 4.4: Car and driver's license ownership (a) of survey respondents and MPN respondents and reasons to possess one or multiple cars (b) of survey respondents

4.2.2 Transport pattern

Commuting travel mode - Looking at the actual and preferred transport mode of both samples in Figure 4.5, it can be noticed that already a large share of respondents in a car-free area are using a bicycle as their main commuting transport mode. This indicates that possibly a residential self-selection has taken place in car-free development area, resulting in inhabitants that purposely choose to live close to their job location. Other commuting options that are used by respondents are by train or by car. Contrarily, within the MPN sample more than half of the respondents are commuting by car. Nevertheless, within both samples people respond that their preferred commuting mode is by bicycle. The difference between the two samples is that within the collected sample the respondents are currently using a car or train to commute and instead want to use a bicycle. In the MPN sample however, a large group of respondents is categorized as either a car user or is currently commuting in non-observed transport modes.

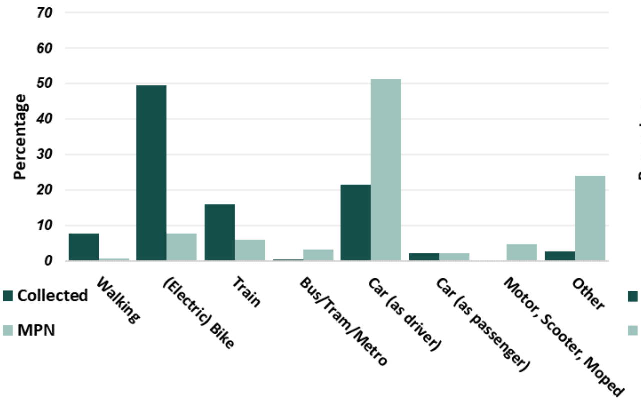


Figure 4.5 (a)

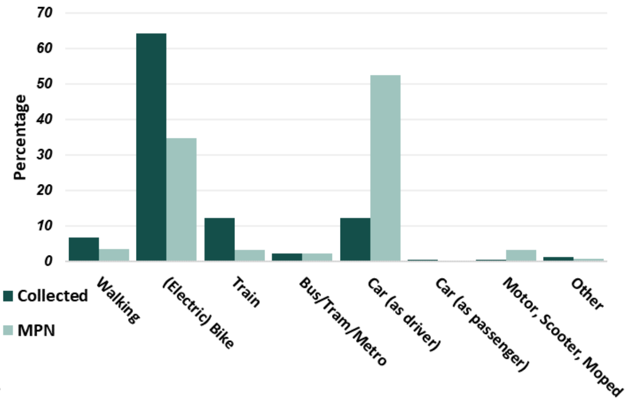


Figure 4.5 (b)

Figure 4.5: Current (a) and preferred (b) travel mode of survey respondents and MPN respondents

Satisfaction of commuting trip - Similar to their actual and preferred commuting mode, respondents in the collected sample have been asked about their satisfaction regarding their travel mode and travel time. As seen in Figure 4.6, respondents that walk or bike towards their job location are relatively satisfied, both in terms of their travel mode and travel time. Interestingly, train transport is perceived unsatisfactory by respondents, especially regarding travel time. A possibility to this level of satisfaction could be that within train transport a lot of time is lost at transfers and stops, which could be perceived as wasted time by respondents in which their vehicle is not moving. Due to the small number of respondents that use a bus, tram or metro to reach their job, no statements should be made about this group. Car users within the sample declare that they are relatively satisfied with their travel mode and travel time, which is contrasting to the preferred change from car transport to bicycle transport as shown in Figure 4.5. A possible explanation is that car users do not have the possibility to use a bicycle to reach their job destination, as the distance is too large between their residence and their job location.

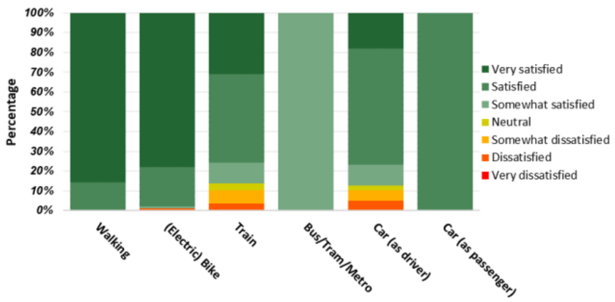


Figure 4.6 (a)

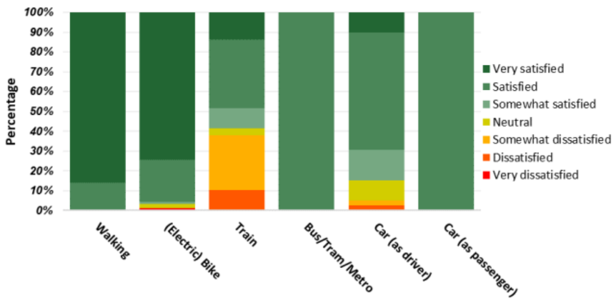


Figure 4.6 (b)

Figure 4.6: Satisfaction of commuting travel mode (a) and travel time (b) of survey respondents

Transport usage - Examining the usage of the different transport modes in Figure 4.7, it can be distinguished that respondents are most frequently using their bike. Car usage is in line with car ownership, with half of the people using their private car to a certain extent. The figure however also shows that respondents that use a car often use this car multiple times a week. Shared cars on the other hand are barely used by respondents, while more than 80% of the respondents answer that a shared car is available within 15 minutes of their residence. Respondents do not use and have less knowledge about the presence of other shared modes within their neighbourhood. Around half of the respondents do not know whether these modes are available, possibly also due to the relatively recent introduction of these modes. As the municipality of Utrecht tries to promote the use of shared modes among residents and actively implements car-free modes in the Merwedekanaalzone, challenges could arise regarding the actual usage of these shared modes in car-free development areas.

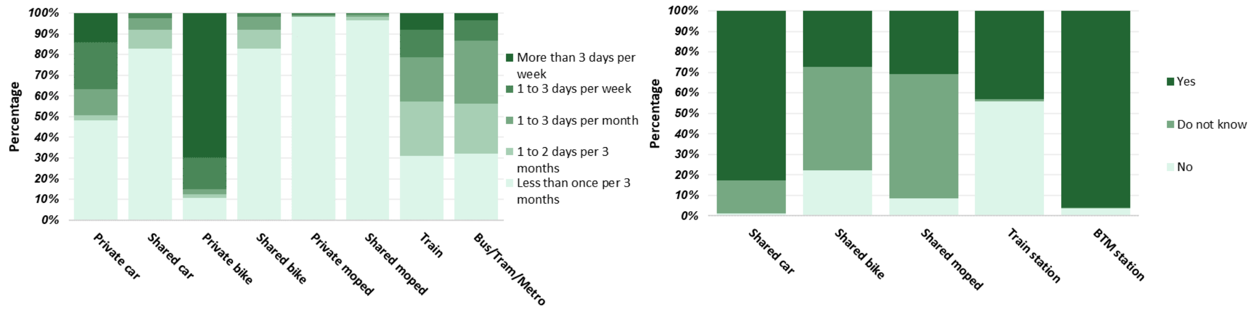


Figure 4.7 (a) **Figure 4.7 (b)**

Figure 4.7: Usage of private and shared transport modes (a) and presence of public and shared transport modes within 15 minutes walking (b)

Transport mode attitude - The attitude of respondents towards the different transport modes, as depicted in Figure 4.8, shows that not only the transport mode itself but that also the type of person that uses the transport mode is influential in the attitude that a person has. Respondents have the best attitude towards bike transport, although very different attitudes can be seen between a regular bicycle and an electric bicycle. Differences can also be seen within the different options for car transport. Using a shared car with acquaintances is perceived most positive, while individual private car transport is still perceived more positive than using a shared car that is also used by strangers. Furthermore, other sustainable transport modes, being train and BTM, are perceived more positive, while the unsustainable and disturbing transport modes, being moped and motor, are perceived negative to very negative.

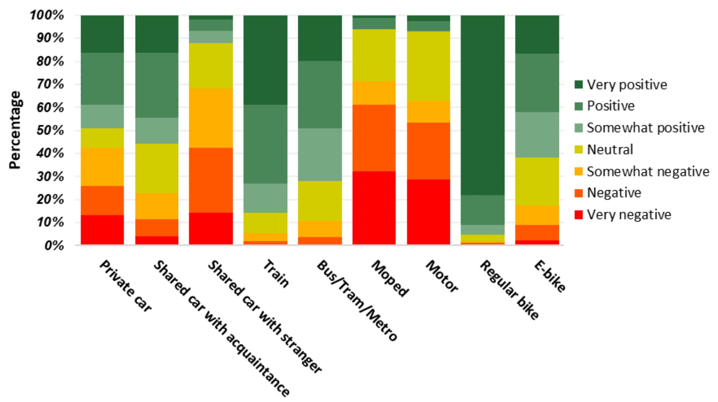


Figure 4.8: Attitude towards different transport modes for survey respondents

4.3 Model estimation

With the use of the discrete choice model in the survey, as described in section 3.2, a latent class logit (LCL) model is generated. This model is capable of determining the relative influence of the trip characteristics in a public-transport trip, which is used in a later stage of this research to determine accessibility. Within this model, multiple latent classes as well as different socio-economic indicators have been considered. A model with three latent classes showed to be best describing the data, which is illustrated in Table 4-2. Each class contains coefficients for the different trip characteristics, while also for every class the probability of belonging to that class can be determined using the socio-economic coefficients as determined for that particular class. Based on these socio-economic characteristics, different individuals will have different likelihoods to fall in the different classes and will thus perceive accessibility differently. While socio-economic characteristics cause individuals to belong to the different classes, the underlying motive of an individual to value trip characteristics differently cannot be captured. Hence the classes being called latent.

Table 4-2: Latent Class Logit Model

	Coefficient	Class 1		Class 2		Class 3	
		Estimate	P-value	Estimate	P-value	Estimate	P-value
Trip characteristics	Costs	-5.56 E-2	0.039*	-5.22 E-3	0.740	-3.56 E-1	0.089
	In-vehicle time	-6.57 E-2	0.000	-4.95 E-2	0.000***	-4.51 E-2	0.147
	Walking time	-9.81 E-2	0.014*	-2.82 E-1	0.000***	-1.52 E-1	0.036*
	Waiting time	-6.93 E-3	0.866	-1.10 E-1	0.000***	-4.53 E-1	0.043*
Socio-economic characteristics	Constant	Reference group		-6.68	0.000***	-5.60	0.000***
	Income level			4.33	0.000***	2.21	0.001**
	Age			1.24 E-1	0.000***	1.35 E-1	0.000***
	Number of cars owned			-4.58	0.000***	-3.73	0.000***
	Household size			-1.91	0.000***	-1.11	0.006**
AIC	544.92	*	Significant on a 90% level				
BIC	678.70	**	Significant on a 95% level				
LL	-266.2	***	Significant on a 99% level				

To better illustrate the relative importance of every trip characteristics on the probability that a trip is being made, Figure 4.9 shows the decay function of every characteristic in the different classes. Based on these decay functions accessibility can be determined using the probability that a trip is being made, relative to the average likelihood of an individual to fall in the different classes.

Within Class 1, it can be noticed that surprisingly waiting time is perceived less negative than all other time coefficients, although it can be noted this coefficient is not significant. All the coefficients are perceived relatively equal compared to the other classes, with respectively costs, in-vehicle time and walking time being perceived slightly more negative.

Trip coefficients of Class 2 show that costs are of very low importance for individuals belonging to this class. As this coefficient is very small and therefore is of no influence for these individuals, this also explains the low significance of this coefficient. Within the same class it can be distinguished that both walking time and waiting time are perceived more negative compared to in-vehicle time. This is in line with the literature, which states that out-of-vehicle time is often perceived twice as negative compared to in-vehicle time.

Decay functions belonging to Class 3 show, except from in-vehicle time, a very steep decline. This causes accessibility to decrease rapidly for this class, therefore causing individuals that have a high chance of belonging to this group to perceive worse accessibility compared to individuals that belong to the other two classes. The steep decline for all trip characteristics also suggests a very negative association with travelling in general for this class.

Table 4-3 provides a summary of the different classes. To better illustrate the differences between the classes, as well as giving a better interpretation of a person within a certain class, particular names can be given to the different classes. Class 1 can be seen as a class in which travelled distance in terms of in-vehicle distance or walking distance is relatively important. This class can therefore be labelled as a distance-resisting class. Contrarily is Class 2 a class in which costs are unimportant and especially out-of-vehicle time is important. This class can therefore be seen as a time-resisting class, in which time not spent on travelling but instead on walking or waiting can potentially be associated with wasted time. Class 3 is a class in which all characteristics related to travel are perceived negatively, this class can thus be named as a travel-resisting class as this best depicts their perception of travelling.

Table 4-3: Summary of trip characteristic importance

	Travel time	Travel cost
Class 1	Increased distance perceived negatively, waiting time less important	Costs averagely important to trip probability
Class 2	Out-of-vehicle time perceived more negative compared to in-vehicle time	Costs not important to trip probability
Class 3	Out-of-vehicle time perceived more negative compared to in-vehicle time. All characteristics perceived negatively compared to other classes	Costs very important to trip probability

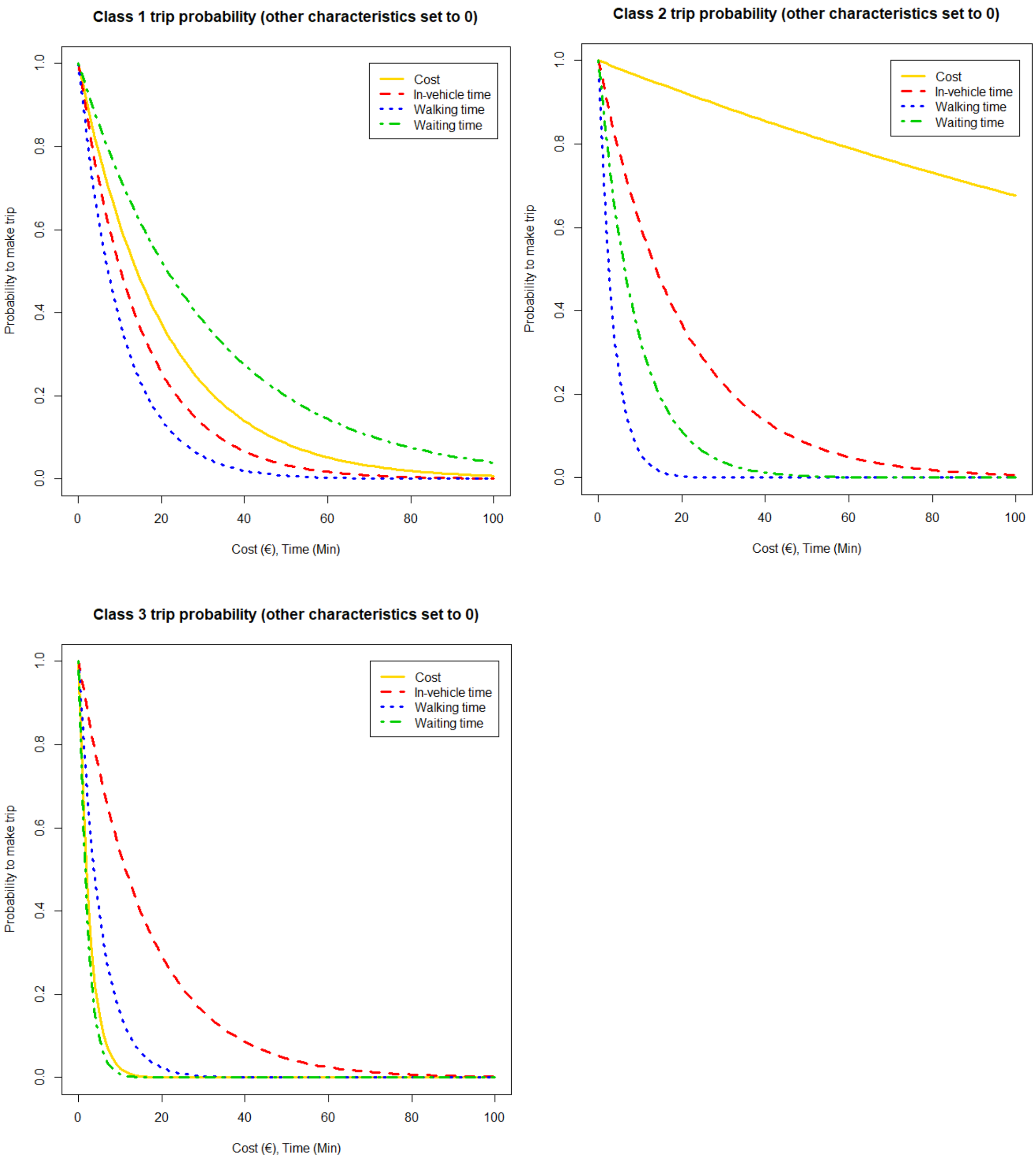


Figure 4.9: Probabilities to make a trip in different latent classes

To better illustrate the differences between classes, Figure 4.10 shows the probability of a person with specific socio-economic characteristics to fall in a certain class. As seen in the figure, individuals that possess a low age and income have a relatively high chance to fall in Class 1, while owning many cars or being part of a household with many persons also increases the probability to fall in Class 1. The combination of a large household and a high number of owned cars indicates that in large households a car is important to fulfil the accessibility needs of every household member.

Socio-economic characteristics that cause a considerable chance to fall in Class 2 are rather opposing to the characteristics that increase the chance of falling in Class 1. High-aged and high-income households, which are often related, cause an increased chance to fall in this class. This is in line with the insignificance of the cost attribute in this class, as a higher income gives relatively less importance to the costs of a public transport trip.

Probabilities to fall in Class 3 remain relatively low, despite the distribution in socio-economic characteristics. Class probabilities only exceed probabilities of the other two classes when households have an average income. Yet, due to the described utility coefficients present in this class, accessibility is highly influenced by the probability to fall in this class.

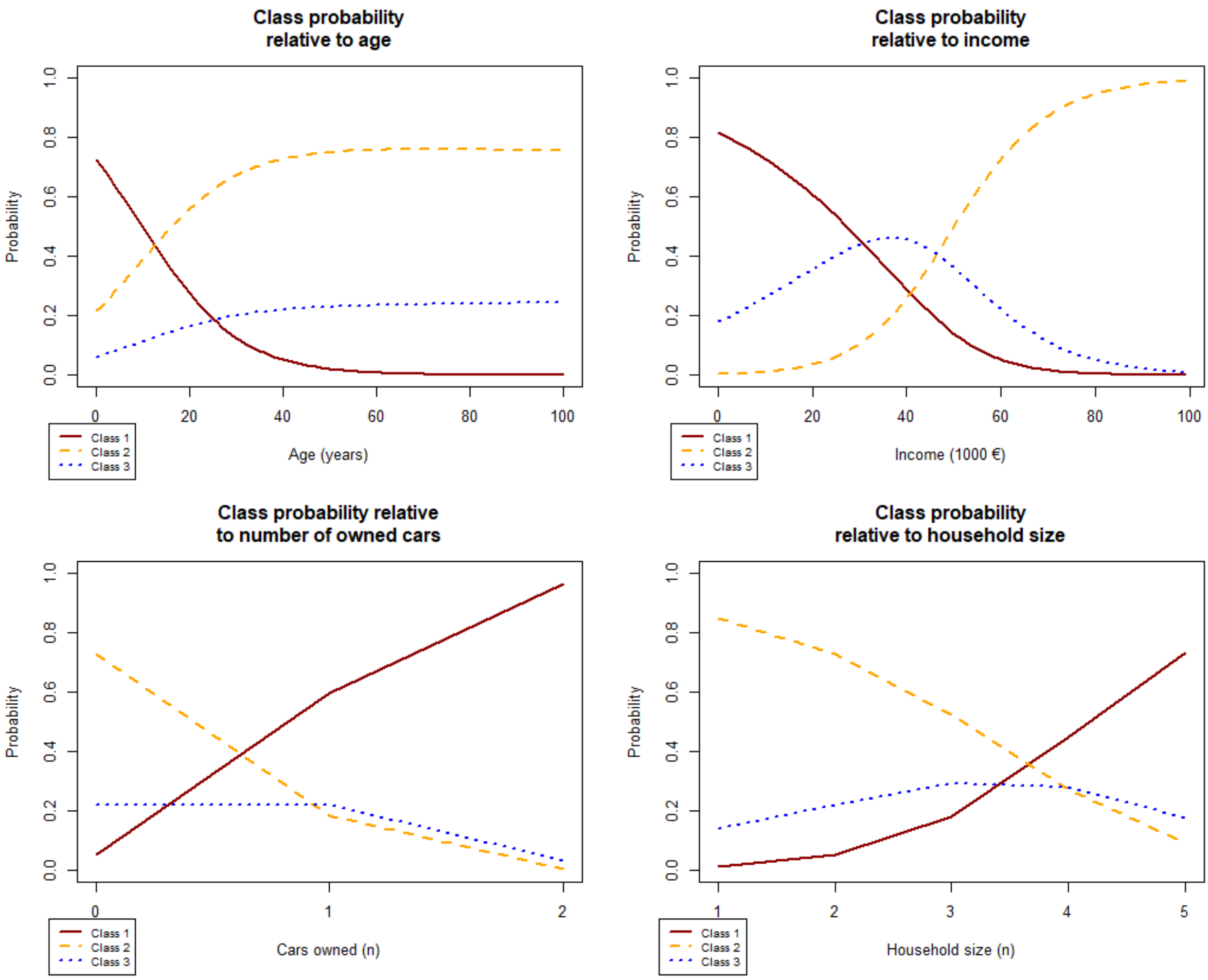


Figure 4.10: Class probability based on socio-economic characteristics

To define accessibility for different population groups, these groups need to be determined based on their socio-economic characteristics. Note that there is a difference between classes and groups. Classes refer to the three classes for which utility coefficients have been determined based on the discrete choice experiment, whereas groups refer to the population groups for which accessibility is being determined. Within the remainder of this research classes will refer to one of the three classes for which a latent class logit model has determined trip characteristics, while groups will refer to the different population groups for which accessibility have been analysed.

The municipality of Utrecht has distinguished several population groups for which they state to provide residences in the Merwedekanaalzone. Figure 4.11 shows the distributions of the socio-economic characteristics that are used to define these population groups, determined by the output of the survey. These distributions are used as input to define the probabilities of a certain group to fall within the different classes. Based on a simulation, in which 10.000 draws define the characteristics of a household in a car-free development area. As a result, Figure 4.12 shows the probability of different population groups to fall in the different classes.

It can be noticed that senior adults have a very small chance to fall in class one, with relatively high chances to fall in in class two or three. This is in line with the importance of walking time in class two especially, for which senior adults more often have difficulties with. Starters and families have relatively large distributions in class one and two, while these groups have similar small probabilities to fall in class three. This indicates that possibly socio-economic characteristics differ largely from one household to another, causes large differences within the probability of belonging to a certain class. Another possibility is due to class one and class two being relatively similar in terms of their socio-economic explanatory variables, therefore already giving large variations in class probabilities when small variations are present between households.

Very large differences in class probabilities can be found between high- and low-income households. High-income households have a very high chance to fall in class two, which is in line with the relatively small influence that costs have in this class. Low-income households on the other hand a have a higher probability to fall in either class one or three, in which costs are relatively more influential.

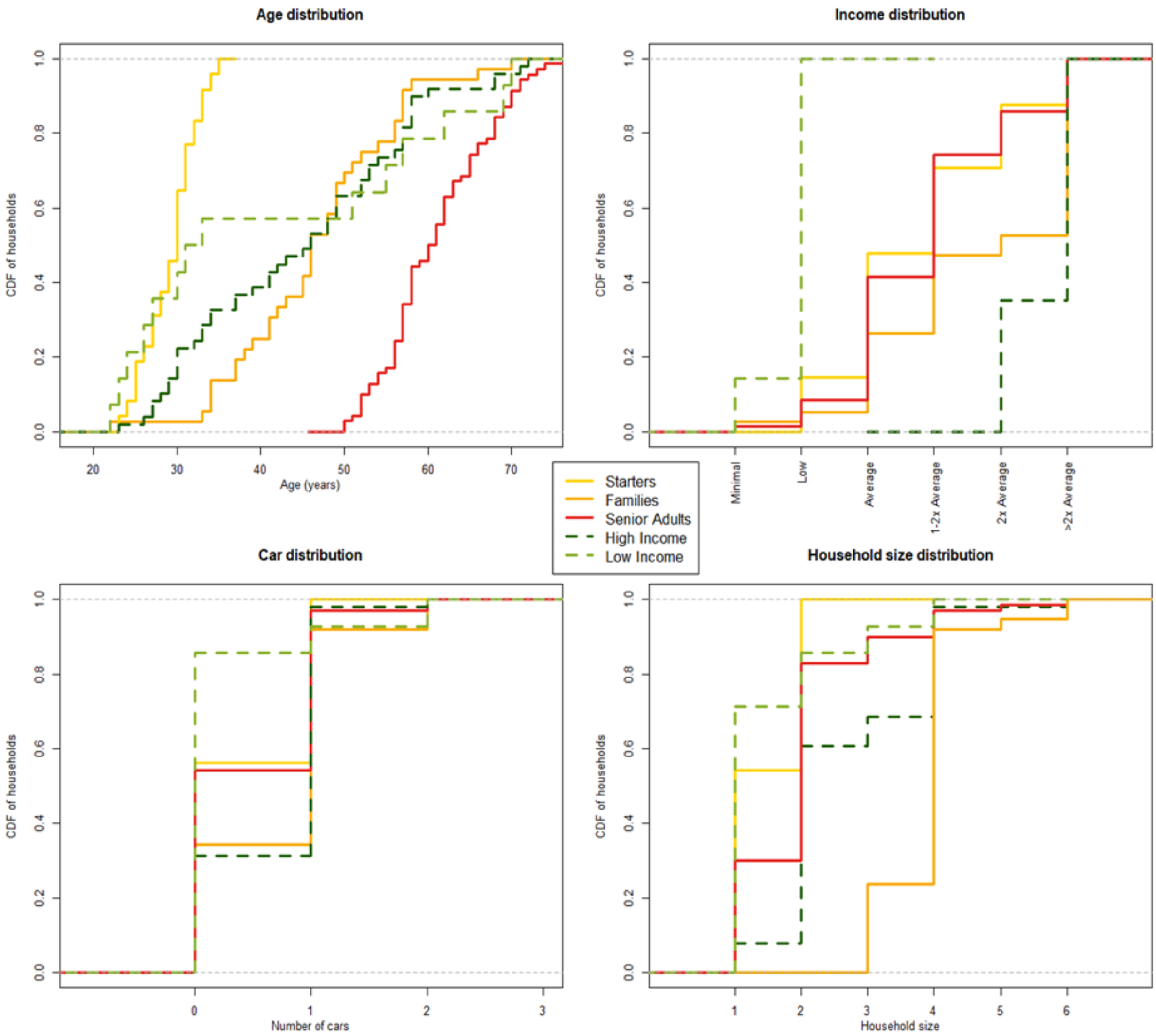


Figure 4.11: Socio-economic distributions of different classes

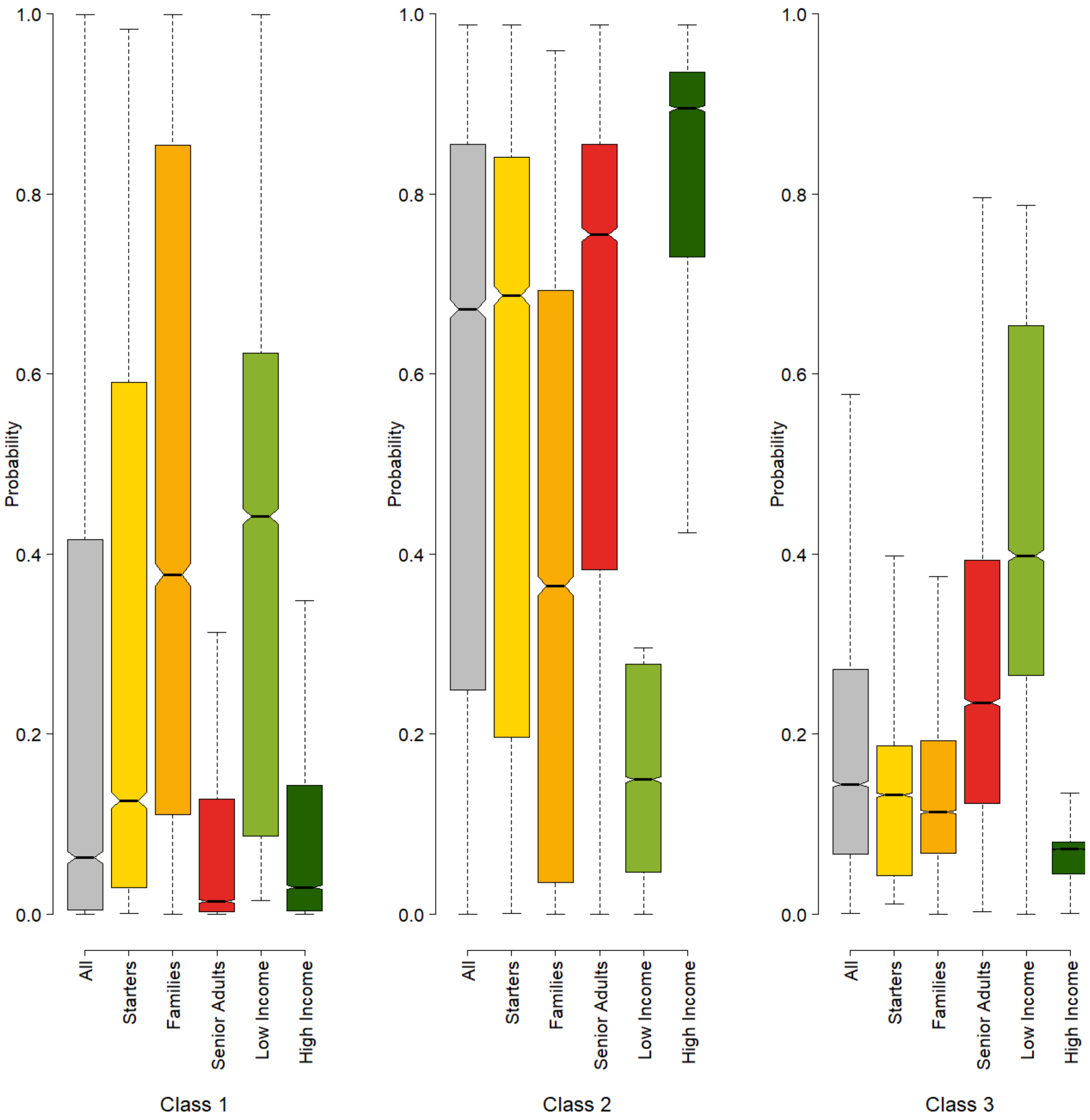


Figure 4.12: Class probabilities for different population groups

5 Results

Within this section, accessibility will be evaluated. First, accessibility results in a base scenario will be evaluated based on the earlier described regression model and the GIS model. This will be followed by an evaluation of the different proposed measures and their implications on accessibility.

With the knowledge obtained from this section, answers to the following sub-questions can be found.

2. What is the current state of job accessibility for a multi-modal car-free transport option in the Merwedekanaalzone, relative to the perception of the population groups?
3. What is the influence of proposed measures to accessibility of different population groups in the Merwedekanaalzone?

5.1 Accessibility in a base scenario

From the GIS model, travel characteristics from the Merwedekanaalzone to the traffic analysis zones have been found. In Figure 5.1 these trip characteristics can be distinguished for Utrecht and its surrounding areas. As seen in the figure, the Merwedekanaal is already forming a barrier between the neighbourhoods on adjacent sides of the canal. Both in terms of travel time and travel costs, areas located on the western side of the Merwedekanaalzone are advantageous compared to locations on the eastern side of the project area. Moreover, it can be noticed that there is no clear connection between travel time and the presence of light rail within an area. Most of the corridors that are currently visible within the figure can be related to existing bus lines instead of light rail lines, indicating that light rail in its current form is related to higher travel times and is therefore possibly not used frequently by inhabitants of the Merwedekanaalzone.

Figure 5.2 provides an overview of the total travel time not only to Utrecht itself but also to other parts of the Netherlands. Within the figure existing train lines are clearly visible, which can be explained by the excellent train connections that Utrecht Centraal provides. The fact that train transport is the only suitable transport mode to travel larger distances also emphasises the need for quick connections to Utrecht Centraal for inhabitants in the Merwedekanaalzone. Providing these connections reduces travel times to nearly all major cities in the Netherlands, increasing the traversable area significantly. Especially considering the polycentric nature that can be distinguished within the Randstad, a potentially large increase in job opportunities can be reached if better connections to these major cities are provided.

Travel costs when using public transport, as seen in Figure 5.3, are relatively high in the Netherlands. In the figure it can be noticed that travel costs increase significantly even at relatively short distances. Looking at trips of longer distance however, it can be noticed that travel costs stagnate. Due to the travel costs for train transport being capped at a certain limit, travel costs remain the same when a certain travel distance is exceeded. This is potentially a large barrier for both employees as well as employers, reducing the feasibility to use public transport as a daily form of short distance commuting and instead advantaging long distance train travel.

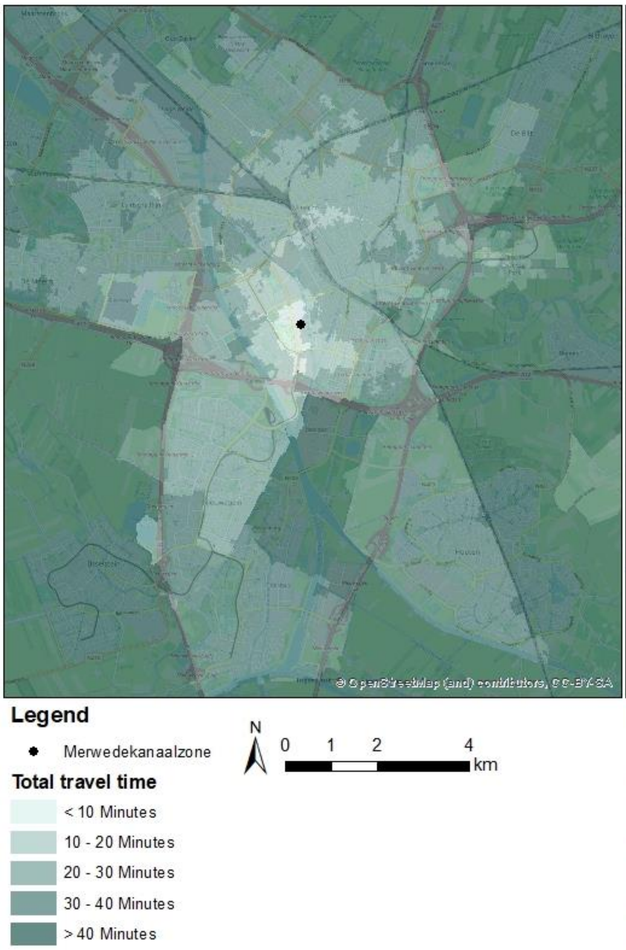


Figure 5.1 (a)

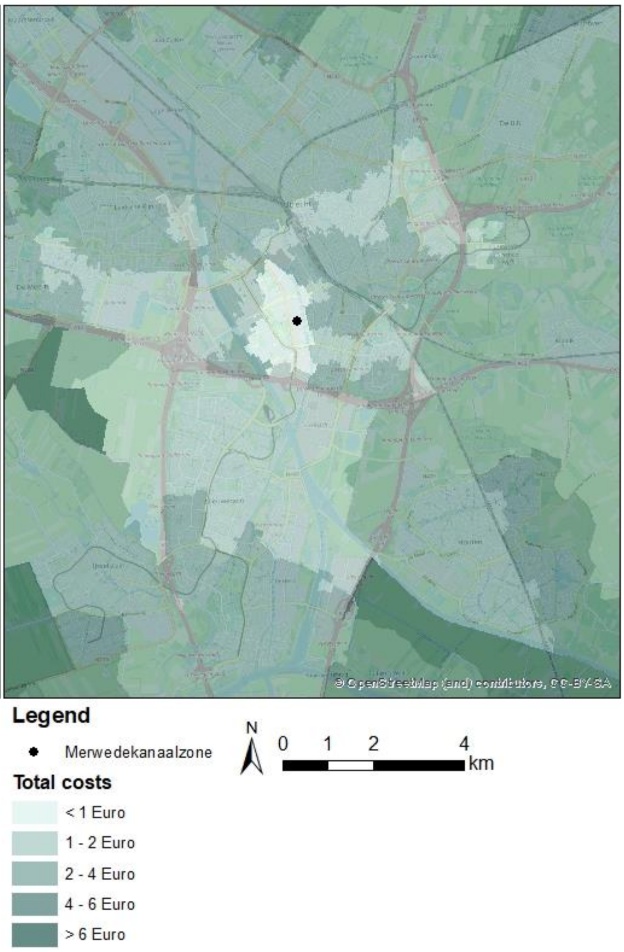


Figure 5.1 (b)

Figure 5.1: Total public transport travel impedance in terms of travel time (a) and travel costs (b)

Figure 5.2: Total public transport travel impedance in the Netherlands in terms of travel time

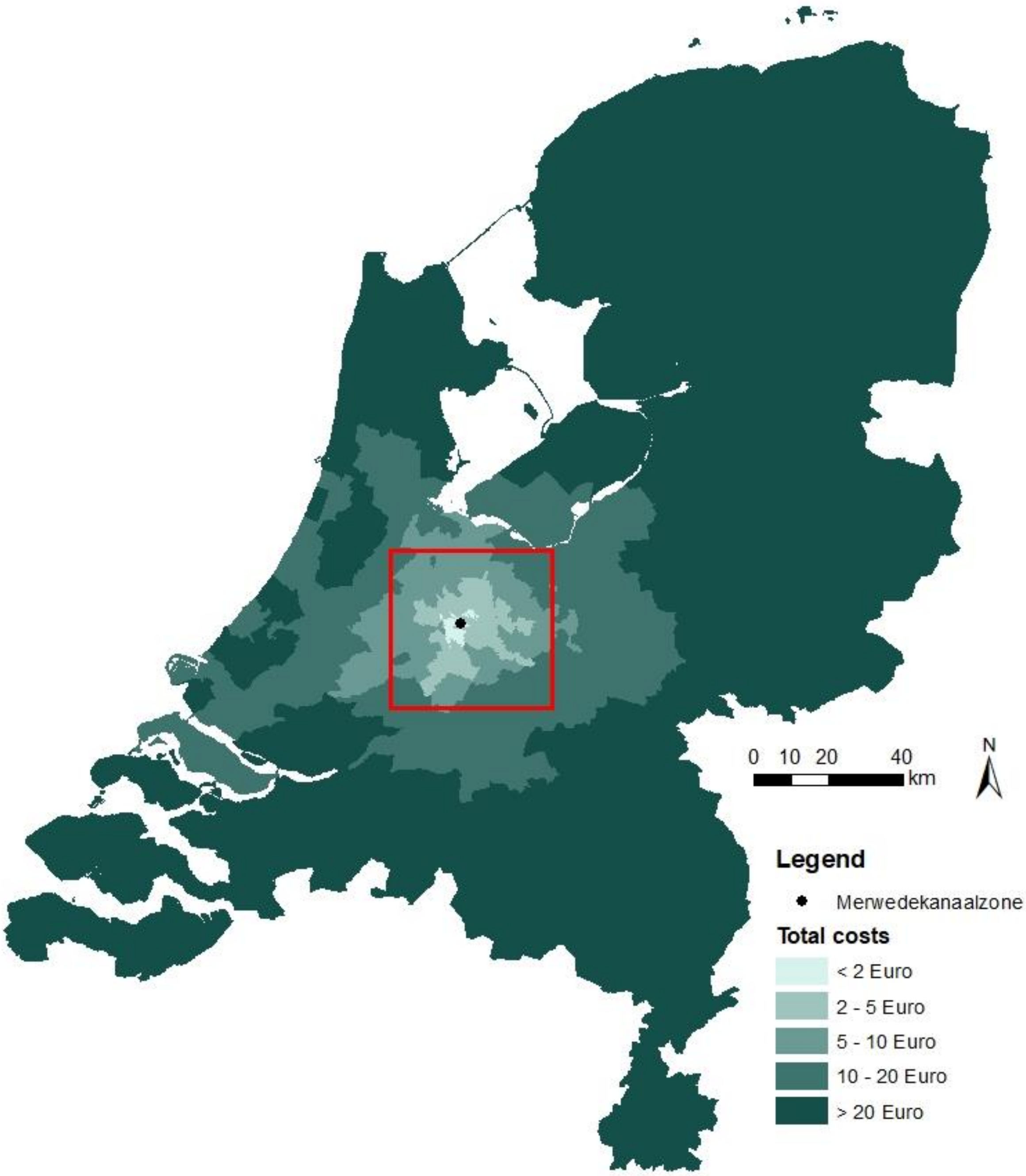


Figure 5.3: Total public transport travel impedance in the Netherlands in terms of travel costs

A combination of the trip characteristics from the Merwedekanaalzone to the traffic analysis zones and the utility functions from the estimated LCL model is used to determine accessibility for the three different classes. Provided job accessibility is therefore dependent on three different parameters. First the number of jobs that are available within the traffic analysis zone, as discussed in Section 3.4.2, secondly the trip characteristics from the origin zone to the destination zones and finally the decay functions of the different classes with respect to the relative consideration of the trip characteristics in the different population groups.

As a result, Figure 5.4 illustrates the provided job accessibility from the Merwedekanaalzone for the different classes in Utrecht. To take into account the difference in size between the zones, accessibility is delineated as the number of accessible jobs per square kilometre. As seen in the figure, the difference in job accessibility between the classes is considerable. In Appendix F, perceived job accessibility in the Netherlands for respectively Class 1, Class 2 and Class 3 can be found.

Within Class 1 many municipalities within the Randstad area provide a broad number of job opportunities, while also numerous opportunities are available within the city and province of Utrecht. Given by the large number of opportunities in other major cities in the Netherlands, this indicates that individuals that fall into this class have no problems travelling far to reach their job location. The relatively high number of accessible jobs in the periphery of the province of Utrecht suggests that a combination of transport modes and thus a large amount of waiting time is still acceptable for these individuals. Some locations close to the Merwedekanaalzone only provide little accessibility. This could possibly be related to the fact that these locations cannot be reached by any type of public transport, therefore causing extensive walking distances which are perceived negatively within this class.

Within Class 2 the number of available job opportunities is reduced significantly, with most of the accessible job opportunities located in large cities or close to the Merwedekanaalzone itself. An explanation for this can be found in the relatively high influence that walking time and waiting time have within this class. For locations very close to the Merwedekanaalzone, waiting time and walking time are small and therefore probabilities to travel remain high. For locations further away, train transport is the main mode of travelling and therefore the number of transfers as well as the waiting time is relatively low. For locations that are too far from the Merwedekanaalzone to reach without a transfer but are too close to be accessible by train transport, a combination of busses is most common to reach the destination. This especially produces a lot of waiting time at transferring stations, resulting in a large decrease in accessibility within this class.

Within Class 3 the number of opportunities diminishes, clarified by the large disutility that any kind of transport gives to this class and which can be noticed within the respective decay functions. This results in only a handful of locations located close to the Merwedekanaalzone being appropriate for individuals that complete fall into this class, providing job accessibility that is low compared to the other classes. Individuals that have a high chance of falling within this class can be seen as persons that prefer to work within proximity of their residence and thus mostly within the city that they live in.

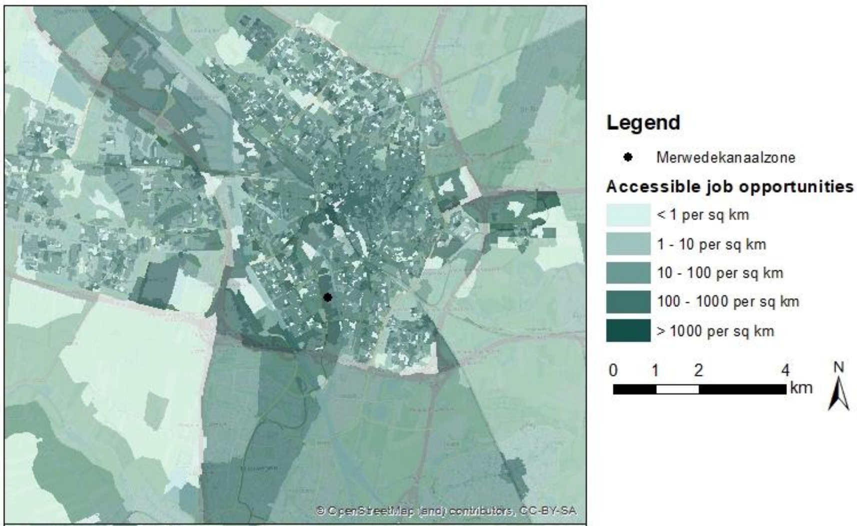


Figure 5.4 (a)

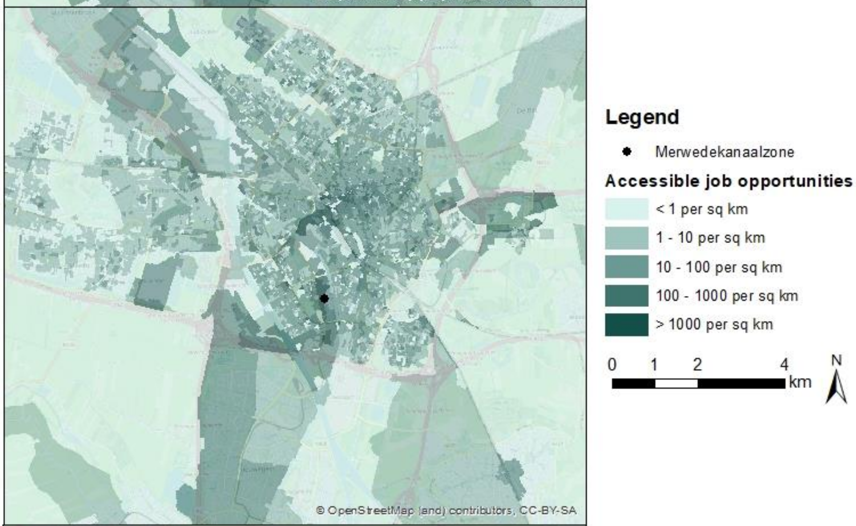


Figure 5.4 (b)

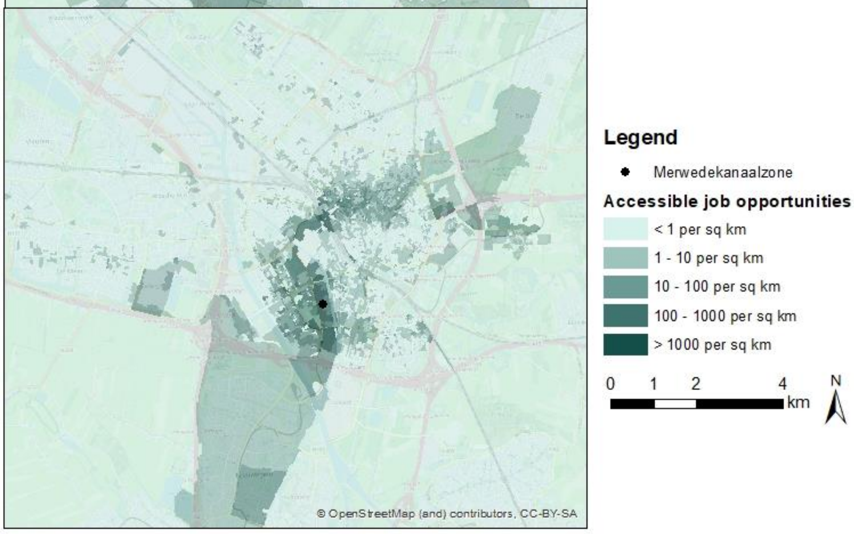


Figure 5.4 (c)

Figure 5.4: Potential job accessibility in Utrecht for Class 1 (a), Class 2 (b) and Class 3 (c) in the Merwedekanaalzone

To provide conclusions on job accessibility for different population groups, Figure 5.5 provides the total perceived accessibility for the distinguished groups in the Merwedekanaalzone. As seen in the figure, families perceive the most accessible jobs, followed by respectively starters and senior adults. This is mostly due to families having a relatively high chance to fall in Class 1, whereas starters and senior adults have a smaller probability to fall in this class. The difference between starters and senior adults can be explained by the high chance of senior adults to fall in Class 3, which provides only a minor number of accessible jobs.

A significant difference in potential job accessibility can be identified between high-income and low-income households. Due to high-income households almost completely falling in Class 2, this type of household does not suffer from the small number of available job opportunities in Class 3 but also misses out on the large number of jobs provided by Class 1. As low-income household on the other hand have a relatively high chance to fall in Class 1 compared to high-income household, this increases the number of available job opportunities for this group.

If, instead of walking, a base scenario is considered in which individuals use a bicycle as their access mode to reach a public transport, a sharp increase in accessibility can be distinguished. For every population group this increase is noticeable, with perceived job accessibility nearly doubling for all population groups. This increase is remarkable, as the change from walking to cycling only affects a minor part of the trip between origin and destination. It is however in line with the literature, which concludes that bike-and-ride trips provide twice the number of accessible jobs compared to walk-and-ride (Pritchard, Stępniak, et al., 2019). This emphasises the importance for dedicated cycling infrastructure, both in terms of transport as well as bicycle storage at public transport station.

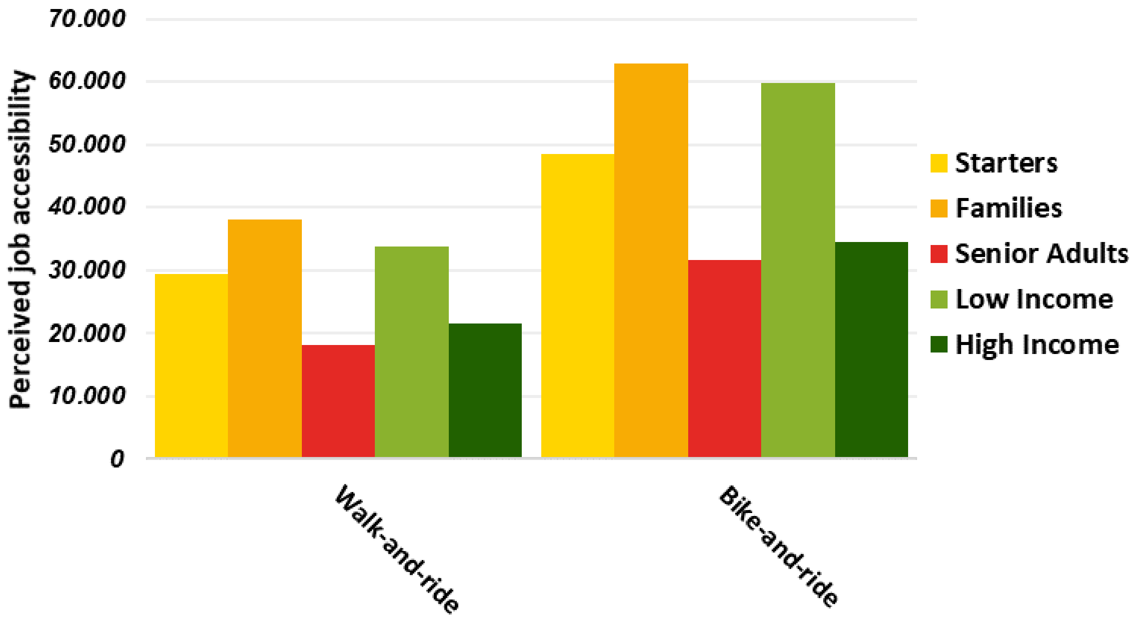


Figure 5.5: Provided job accessibility in a base scenario using walk-and-ride and bike-and-ride

The potential number of available jobs gives a good approximation of the number of opportunities that an individual in the Merwedekanaalzone has access to. However, as stated in Section 2.3.2, other individuals will also compete for the same available opportunities. To include this in the available jobs that an individual perceives to be accessible, the number of inhabitants in the destinating zone as well as coemption based on a Shen Index is included within the accessibility equation. This provides an approximation of the number of available jobs that are not only accessible, but also have the same number of persons competing for this job. Figure 5.6 provides the number of accessible jobs for the different population groups, in case of considering this competition effect using inhabitants of the destinating area. This figure better depicts a real situation, as the number of accessible job opportunities decreases rapidly when a lot of other people compete for only a limited number of job opportunities. Figure 5.7 even better approximates this competition effect, by including competitors not only in the destinating area but also in all other areas based on a decay function.

As seen in the figures, similar patterns compared to accessibility without including competition effects can be noticed. Accessibility for senior adults decreases more rapidly compared to the other age groups, with starters and families perceiving respectively two and three times more jobs to be accessible in case of a walk-and-ride scenario. Low-income individuals on average perceive twice the number of jobs to be accessible in comparison to higher-income households, both in a walking and a cycling situation. This can be related to the relatively high chance of senior adults and high-income households to fall in Class 2. Accessible jobs within Class 2 can mostly be found within large and densely populated cities in the Randstad, while in Class 1 these jobs are also located at the more sparsely populated periphery of the province of Utrecht. In Class 2, compared to Class 1, this causes more inhabitants to compete for the available job opportunities.

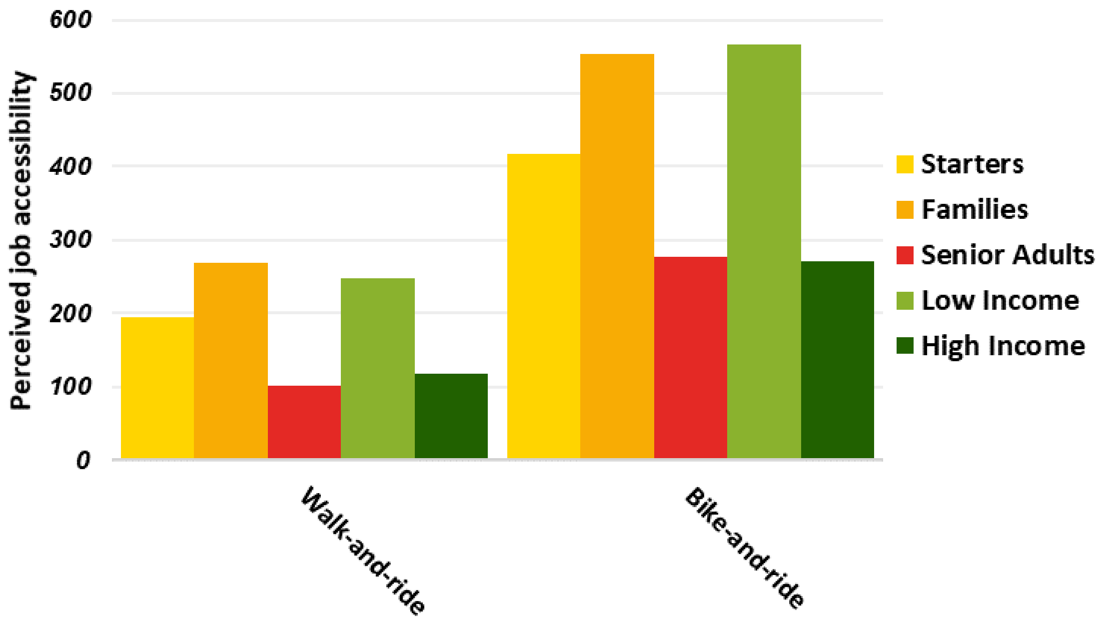


Figure 5.6: Provided job accessibility in a base scenario when inhabitants in the destinating areas are considered

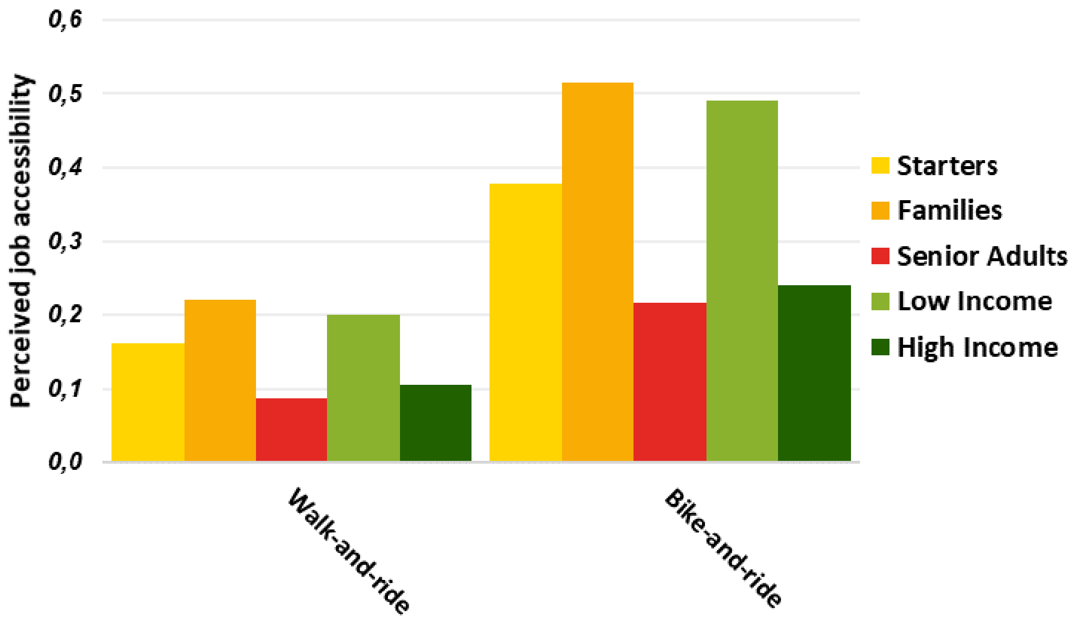


Figure 5.7: Provided job accessibility in a base scenario when competition effects are considered

5.2 Accessibility in a scenario with implemented measures

Now that accessibility within the current situation in the Merwedekanaalzone is evaluated both in terms of population groups as well as in development location, the relative improvement of every measure can be assessed. From Section 3.1.2 measures that have been considered are bridges across the Merwedekanaal, two different tram tracks as proposed by the province and by Mott MacDonald, as well as an improvement of train station Utrecht Lunetten to serve intercity trains from multiple directions.

Figure 5.8 provides the absolute number of accessible job opportunities relative to the perceptions of the different population groups. As seen in the figure, senior adults as well as high-income households perceive the least number of jobs to be accessible after the implementation of every measure. This is caused by the already low accessibility in a base scenario for these population groups. Therefore, in Figure 5.9 the relative increase in job accessibility compared to the base scenario is presented. This displays that also due to the earlier mentioned low accessibility in a base scenario for senior adult and high-income households, the effect of the measures on accessibility is relatively high. Figure 5.10 provides the relative increase in job accessibility when simplified competition effects have been included.

As seen in Figure 5.9 and Figure 5.10, not every measure increases accessibility to a similar extend. From the four measures that can potentially be implemented, extra bridges cause the largest increase in accessible job opportunities which is noticeable in every population group. A possible reason for this increase is the shortened distance towards the train stations located northeast of the Merwedekanaalzone Rijn, decreasing access time to the station significantly. As these bridges are however, in contrast to the other measures, located within the Merwedekanaalzone itself. Therefore the provided increase in accessibility caused by these bridges is only noticeable in the Merwedekanaalzone, whereas the other measures potentially also increase accessibility in other areas in Utrecht.

A notable difference cannot be distinguished between the two different suggested tram routes. Both routes contain an extra track that is directly west of the Merwedekanaalzone, whilst only the route proposed by

Mott MacDonald also contains a track that is adjacent to the south side of the Merwedekanaalzone. This indicates that the track on the west side of the Merwedekanaalzone is preferable in most trips from the Merwedekanaalzone to destinating areas. In case of a competition effect, larger disparities between population groups can be distinguished, with the tram track as proposed by the province of Utrecht finding a larger increase for population groups that absolutely speaking perceive less jobs to be accessible. Also, the origin of the Merwedekanaalzone is located at the centre point of the area within the accessibility model, relatively far away from the Waterlinie track that connects the Europaplein to train station Lunetten. Therefore, when instead of the centre point a location more towards the southern edge of the Merwedekanaalzone is used within the model, on average around 500 more jobs are perceived as accessible in every population group when the tram track proposed by Mott MacDonald is used.

Upgrading Utrecht Lunetten to an intercity station has no effect on accessibility when implementing this measure on a standalone basis. This can be explained by the current tram network, that does not access this train station but is instead providing quick connecting transfers on Utrecht CS. Therefore the station of Utrecht Lunetten is possibly not used frequently by inhabitants of the Merwedekanaalzone, being meaningless when upgrading this station to serve intercity trains without also implementing a new tram route that serves this train station.

In a situation where a combination of measures is implemented, additional accessibility is provided on top of the provided accessibility by the measures on their own. Yet, a combination of measures does not provide an improvement of accessibility which consists of a combination of the increase in accessibility that every measure provides individually. This suggests that the different measures provide an increase in accessibility in a different sphere of influence, but also provide better connections to the same areas as other measures.

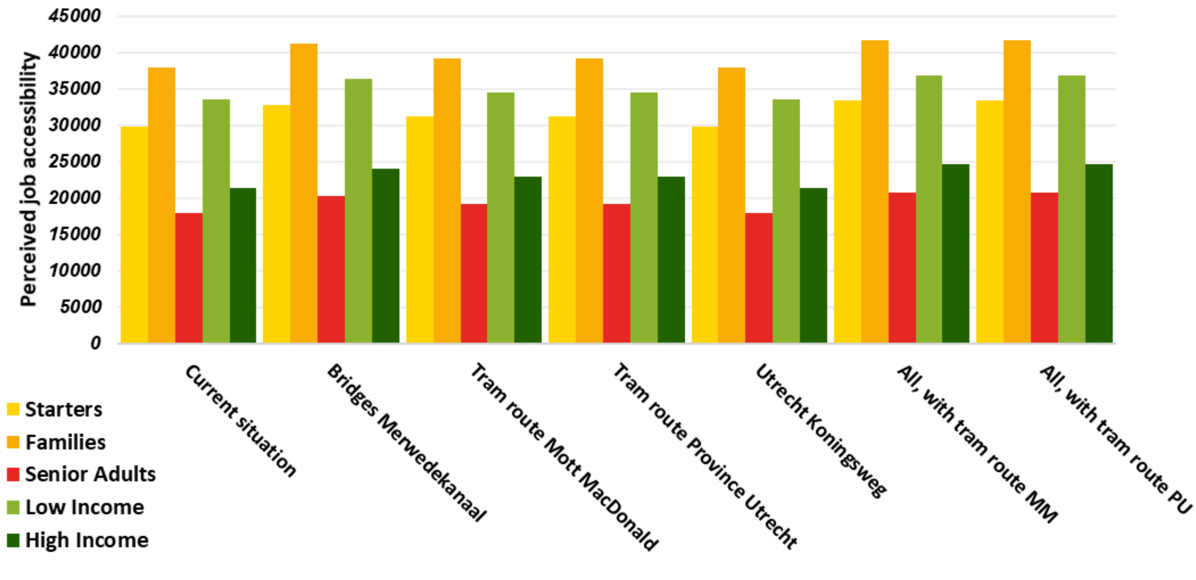


Figure 5.8: Absolute perceived job accessibility for different measures in the Merwedekanaalzone without including a competition effect

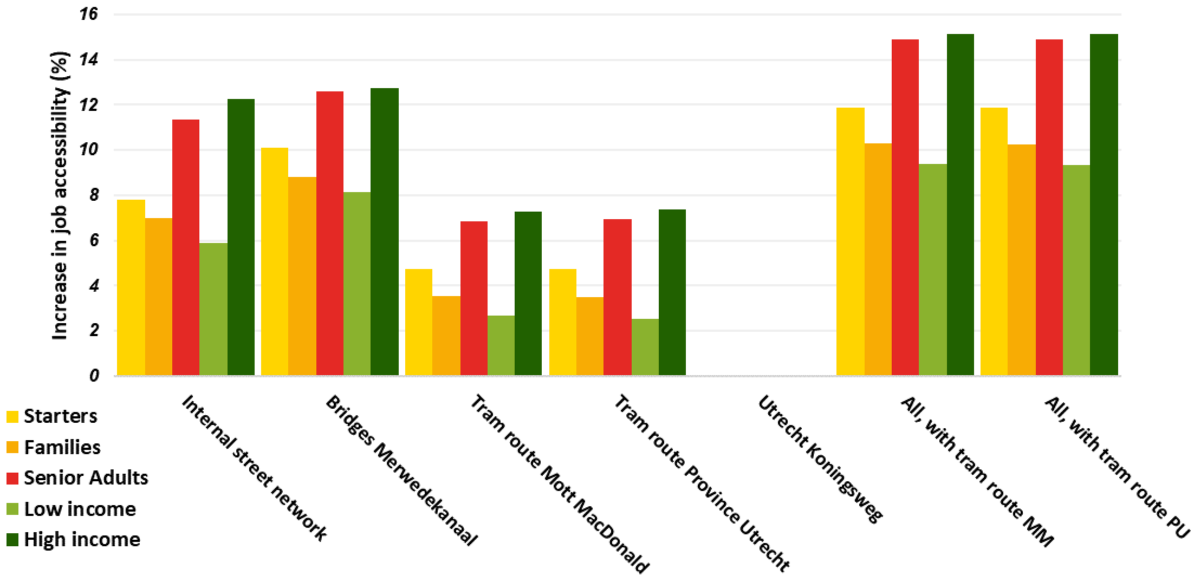


Figure 5.9: Relative increase in job accessibility for different measures in the Merwedekanaalzone without including a competition effect

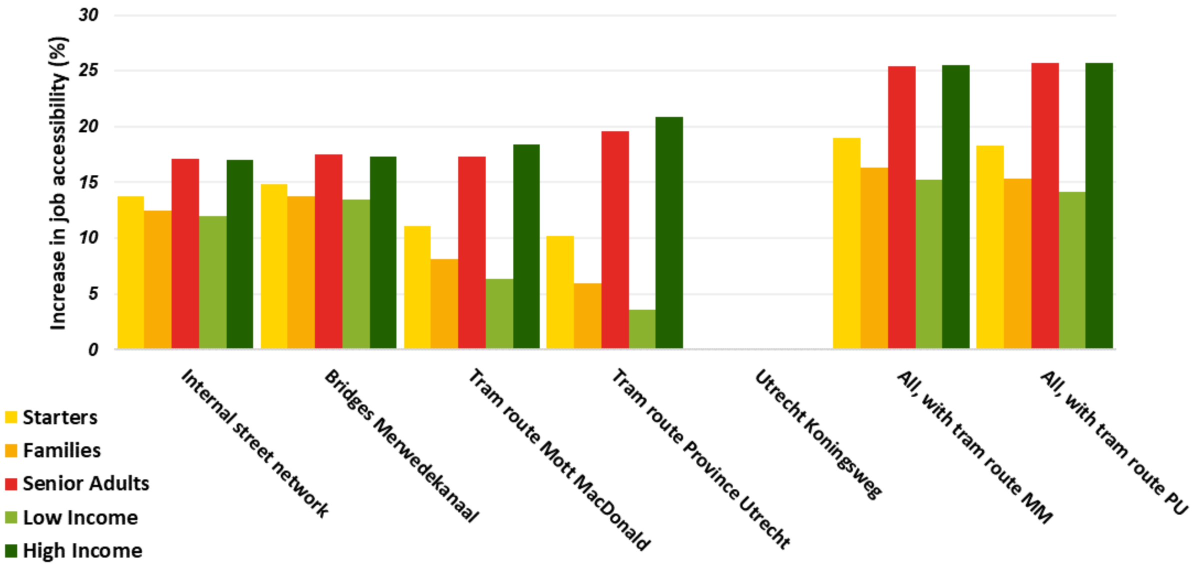


Figure 5.10: Relative increase in job accessibility for different measures with internal competition effects included

5.3 Accessibility analysis between different development areas

In this research, emphasis has been given to the Merwedekanaalzone as a car-free development area. Within Utrecht however, although being developed on a much smaller scale, other development areas are already planned to be car-free as well. Besides, other areas in Utrecht that are currently planned to be developed will possibly in the future also be realised as a car-free development area. Therefore, job accessibility within these different areas can be compared, to investigate the suitability of the Merwedekanaalzone as a car-free development area in comparison to other development areas. It is however important to note that job accessibility is not the only indicator that is important to determine the suitability for car-free development, as many other aspects in other fields need to be considered.

Development areas that have been analysed in Utrecht can be divided into three different categories. Within the first category, being Cartesius and Beurskwartier, the municipality has already proposed a car-free realisation within the area. The second category consist of development areas that are located very close to train stations in Utrecht. Access time is therefore very small at the station of Leidsche Rijn, Lunetten and Overvecht, possibly providing opportunities to develop a car-free residential area at these locations. The third category includes locations that are currently undeveloped but are located close to large business areas with a considerable number of job opportunities. The locations of Papendorp and Science Park could therefore in the future be developed, potentially as a car-free area.

The different locations of the analysed development areas can be seen in Figure 5.11, as well as the average provided job accessibility in the current situation. Figure 5.12 shows the total perceived job accessibility in the different locations with respect to the different population groups. As seen in the figures, development areas that are located on the suburban part of Utrecht provide less accessibility compared to development area within the city. This is mostly due to the transport system, as at the locations of Papendorp and Science Park a lot of job opportunities are present. Within the city itself it can noticed that the Merwedekanaalzone and Cartesius provide relatively few accessible job opportunities. Both results implicate that locations close to major public transport stations provide more accessibility compared to locations further away from public transport stations. Surprisingly, accessibility is higher at the development location Overvecht compared to the Beurskwartier location, even though the latter is located closely to the main train station of Utrecht CS.

Looking at the perceived job accessibility in the different population groups, similar accessibility distributions as within the Merwedekanaalzone can be distinguished. Within every location, senior adults perceive the least number of job opportunities to be accessible. In comparison to the Merwedekanaalzone, the difference in accessibility between low and high-income household is smaller in other areas. Especially in areas within the second category this difference is low, with Overvecht even providing more accessible jobs for high-income households compared to low-income households. This change can be explained by the relatively negative influence of walking time on accessibility in high-income households.

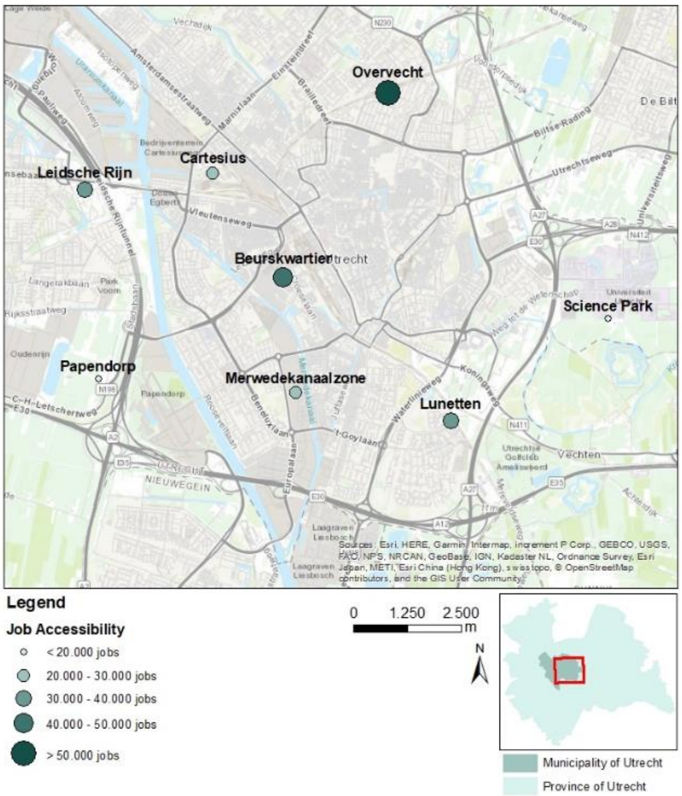


Figure 5.11: Total accessibility for different development areas in Utrecht

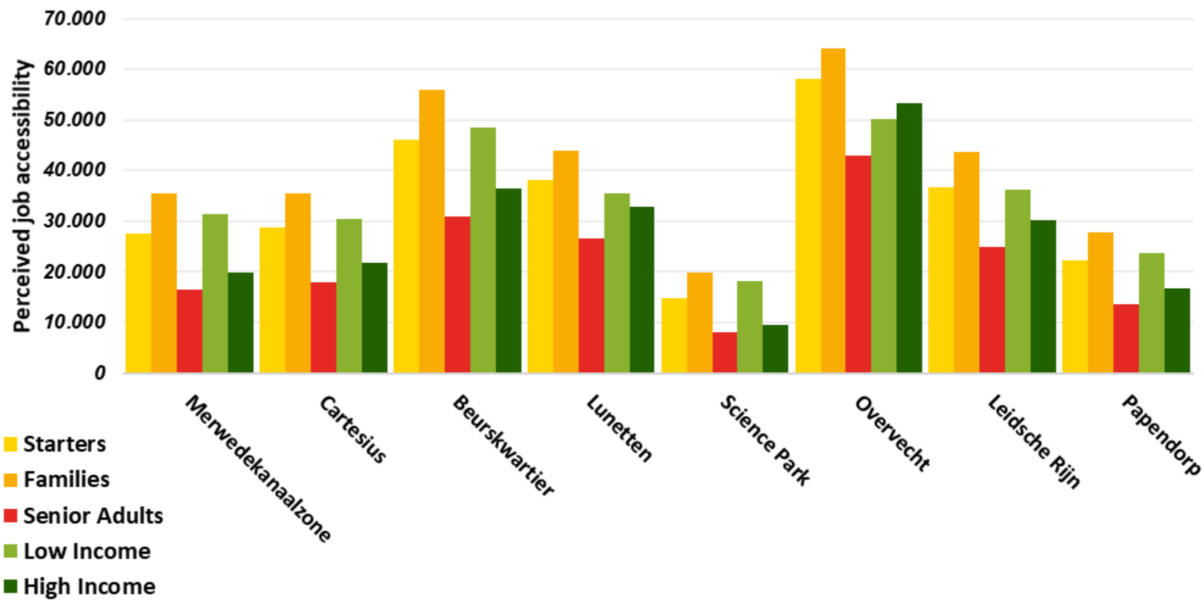


Figure 5.12: Total accessibility for different population groups in development areas in Utrecht

6 Discussion

Within this chapter, the output of the research will be discussed. First, research limitations that potentially influence the outcomes will be deliberated on. Secondly, applications to use the results in future car-free development areas will be evaluated. Finally, further directions for academic research have been provided within this section.

6.1 Research limitations

This section describes the validity of the results and the limitations of the used methodology. A distinction between four different topics can be found: The collected sample of respondents, the used type of experiment in the survey to obtain decay functions, limitations in the accessibility model and limitations in generating the trip characteristics from the Merwedekanaalzone to the destinations.

Collected sample - The sample as collected within this survey consists of inhabitants of three different car-free or low-car areas, though car ownership is not restricted within any of the areas. This sample is capable in providing a model that estimates trip coefficients for the different classes, however there it is not guaranteed that this sample indeed represents a population in a car-free area. As currently no completely car-free area is present within the Netherlands, finding a sample that ensures a correct representation of a population in such a neighbourhood is difficult. Therefore, the collected sample within this research results approximates a population in a car-free development area. Nevertheless, when car-free neighbourhoods like the Merwedekanaalzone or other similar areas in which car ownership is completely prohibited are realised, reapplying the used survey would be useful. Afterwards, if necessary, adjusting the model could potentially improve the results of similar applications in future development projects.

Survey experiment - Within the distributed survey a stated preference choice experiment is used to determine the travel resistance for different trip characteristics. This type of experiment is used in this research due to being better able to determine the individual effect of the different trip characteristics, while also it is much easier to collect. This stated preference represents the choice which the respondent perceives as the choice that best fulfils its needs. However, possibly not all respondents are capable to consciously evaluate the different characteristics and relate these characteristics to each other (Louviere et al., 2000). If a similar study would be performed after the realisation of the Merwedekanaalzone, revealed preference data or a combination of stated and revealed preference could be used instead. Differences between the two methods could capture the mismatch between their rational and their actual behaviour, due to for example habits or due to factors that are not considered within the experiment. Considering the use of both methods to collect data, better conclusions can be achieved and would therefore increase the validity of the research.

Accessibility model - Limitations are also present within the generated model to determine accessibility. First of all the number of included public transport options are constrained. Within the Province of Utrecht all transport modes have been included within the model. Using either bus, tram or train transport is therefore an option when considering a trip from the Merwedekanaalzone to a destination in the province of Utrecht. However, when destinations outside of the Province of Utrecht are considered, only train transport can be used in the model and a general travel impedance is used to depict the final egress distance. This is mostly due to the increased computing power that is necessary, as well as the wide range of different transport operators in the different provinces that would need to be included. As it is expected that most of the trips to these destinations are being made by train transport, it is assumed that a close approximation of the trip characteristics is found using the model as proposed in this research. As a conclusion however, to obtain better approximations of the trip characteristics for routes within the

Netherlands, bus, tram and metro transport within other provinces in the Netherlands could be included within the model.

Within the same accessibility model, a limitation can be found within the assumption that for every mode of public transport the trip characteristics are perceived equally. Within the used methodology, this results in the same utility coefficients of trip characteristics across different types of public transport. This methodology is considered due to the limited amount of data, as well as the restriction in the number of different characteristics that a single respondent can compare. In reality however, trip characteristics are potentially evaluated differently between different modes of public transport. An example of this can be found within the waiting time at a transferring station. An individual probably considers the waiting time at a large station to be more convenient, whereas waiting at a bus stop along a busy street is less convenient and will be therefore be perceived more negatively. The same could go for other characteristics like walking time or in-vehicle time appraisal. If the data collection allows a distinction between types of public transport, including this distinction would increase the validity of the research outcome and should thus be used instead.

Trip characteristic determination - A last limitation can be found in the method to determine the routes between the Merwedekanaalzone and the destinating areas. The used GIS model is only capable of determining a route based on a minimisation towards a single parameter. Within the research, a combination of walking time, waiting time and in-vehicle time is thus included as this optimisation parameter, which is not similar to the used function when determining accessibility. From the literature, a relative perceived disutility of waiting time and walking time compared to in-vehicle time is found. Therefore, within the GIS model, a waiting or walking time twice as large as in-vehicle time was assumed to be of equal importance. As a result, routes with a relatively long waiting or walking time were considered as undesirable routes. Including the relative importance of walking and waiting on the probability to make a trip did better represent the route between origin and destination. In an ideal situation however, the model should minimise towards the route that consists of the highest probability of an individual to make this trip. However, with the currently used software, as well as the development of multiple classes and thus multiple probability functions, this could not be realised within this research.

6.2 Research applications

With the results of this research, policy implications for the Merwedekanaalzone can be analysed. To start, the effect of the measures on the accessibility of different population groups in the Merwedekanaalzone can be analysed. The municipality of Utrecht strives for a healthy urban environment and tries to accomplish this for every inhabitant within their city. Based on the accessibility that each measure provides, the municipality could decide which combination of measures is most important to implement. If the municipality strives for an egalitarian approach, measures that mostly benefit the groups that currently possess the least amount of accessibility could be implemented. If the municipality on the contrast aims for an approach in the total increase of accessibility is considered, measures that provide the most accessibility relative to the investment costs could be considered.

Secondly, as the Merwedekanaalzone is not the only development area in Utrecht where the municipality proposes a car-free location, this research could contribute to finding the optimal location for realising a car-free development area. The results indicate that especially locations close to a train station are suitable locations for car-free development. The municipality could use this research to implement a location suitability indication that specifies the optimal location for a car-free development area. When doing so, it should be noted that job accessibility is not the only indicator to determine a suitable location for a car-free development area. Other important characteristics like the availability of an undeveloped areas or transport characteristics like the capacity of a transport mode are not considered within this research but are likely to influence suitability as well.

Finally, the outcomes of this research could be used to find job accessibility in car-free development in other areas within the Netherlands. This research provides an indication of job accessibility in which the regression model provides the general behaviour of inhabitants in a car-free residential area. This model is therefore also useful in other areas, either when the location is located close to Utrecht or when characteristics of the transport system in the proximity of the location are available.

6.3 Directions for future research

As stated in an earlier part of this discussion, the used sample in this research approximates the population in a car-free residential area. As it is important that the transport system is adjusted to the needs of the residents, further research on this topic could better approximate this sample. An interesting approach could be to monitor residents that move to the Merwedekanaalzone both before their relocation as well as after their relocation. If there is no notable difference in terms of travel pattern for residents that relocate to the Merwedekanaalzone, this could indicate that residential self-selection is taking place in a car-free development area. On the other hand, if a difference is noticeable between the travel patterns before and after a relocation to the Merwedekanaalzone, this indicates that travel patterns change when moving to an area that is car-free.

As the municipality especially desires to reduce the number of cars on the surrounding streets of the Merwedekanaalzone. A second potential direction for future research on the topic of car-free development is understanding the change in car ownership when moving to a car-free neighbourhood. From this research it can be noticed that car ownership is already low in areas that are labelled as car-free or low-car, with especially a low number of second cars being present in household. Within the outcome from this survey however, many respondents answered that owning a car provides a certainty of travelling when the situation asks for it. Future studies could help in further examining car ownership in car-free and low-car areas, and how to obtain a similar certainty of travelling using public transport modes or a form of shared transport.

7 Conclusions

This chapter reports on the conclusions of this research, which are based on the earlier discussed results. It first provides answers to the different sub-questions that have been formulated in the introduction of this report, after which an answer to the main research question will be given.

The main research objective of this research is formulated as follows:

Develop an accessibility model in car-free development that is able to evaluate trip characteristics and job accessibility with respect to the travel preferences of different population groups.

To obtain insights on the provided objective of this research, every sub-question is answered separately within this chapter.

1. How do individuals that opt on living in car-free neighbourhoods in the Netherlands differ from an average household in the Netherlands?

The first research question of this research focusses on the type of inhabitants in a car-free residential area, as well as their travel patterns. To determine these characteristics, a survey is spread in three residential areas in the Netherlands that best approximate a population in a car-free development area. The answers from these respondents are compared with the Mobility Panel Netherlands (MPN) survey, an annual survey that collects travel patterns and socio-economic characteristics in household throughout the Netherlands.

The results show that car ownership remained relatively high within the observed car-free areas. Although all the areas are labelled as a neighbourhood in which car transport is not desired, still over half of the households own one or more cars. The number of households that own multiple cars is however limited, with less than 5 percent of households owning multiple cars in comparison to nearly 30 percent in an average Dutch household. The shift from owning multiple cars to owning only a single car is partly caused by inhabitants perceiving the need to own a car to guarantee a certainty of travelling, while for occasional transport a second car is no longer necessary. Other reasons for inhabitants to still own a car are related to the perceived increased mobility that a car provides or the minimal amount of effort that is needed to reach the destinations of respondents.

Socio-demographic results show that in the investigated areas many respondents are (self-)employed and that high-income households are overrepresented, with over 30 percent of household earning twice the average annual income or more. This could potentially be caused by the relatively high costs of public transport in the Netherlands, but is more likely to be explained by the high prices of residences in the observed car-free residential areas. Children are relatively less likely to be present within the investigated areas, with both single parent families as well as couples with children being underrepresented in the survey results. This can be traced back to the increase in locations that need to be accessible when children are present in a household. This therefore decreases the chance that living in a car-free residential area is a viable option for a household in which children are present.

In line with expectations regarding car usage in the observed neighbourhoods, the transport pattern is different from the results of the MPN survey. Within the actual commuting travel mode in car-free development, over half of the respondents use an (electric) bike to reach their job. As many jobs are reachable by bike, this indicates that inhabitants in car-free development areas deliberately choose to be employed close to their residence. Even though shared cars are often implemented in car-free development areas, almost none of the respondents use a form of shared transport on a regular basis.

2. What is the current state of job accessibility for a multi-modal car-free transport option in the Merwedekanaalzone, considering the perceptions and preferences of different population groups?

According to the literature, the main characteristics that influence accessibility in a multi-modal public transport trip are travel time and travel costs. As within the travel time component different characteristics are perceived differently, travel time can be assimilated into the underlying characteristics walking time, waiting time and in-vehicle time. The literature states that taste heterogeneity is present between the disutility that an increase in one of the characteristics provide, with waiting time and walking time providing twice the disutility that in-vehicle time provide, whereas the disutility that travel costs provide being mostly dependent on the financial situation of an individual.

A stated choice experiment distinguishes the relative disutility that each of the characteristics provide for different population groups. A latent class logit model distinguishes three latent classes that each provide a distinct disutility for every trip characteristic, for which the probability to fall in a certain class are based on the socio-economic characteristics of an individual. In Class 1 the disutility that an increased travel distance gives is most important in determining trip probability, in Class 2 an increased out-of-vehicle travel time contributes the most to a reduction in trip probability, while in Class 3 an increase in any of the trip characteristic reducing the probability of making a trip significantly. Differences between classes and thus individual taste make it difficult to determine a general conclusion for the relationship in provided utility between in-vehicle time, out-of-vehicle time and costs.

Four different socio-economic characteristics are found to be influential to change the probability to be included in a particular class, being age, yearly household income, household size and car ownership. Old-aged and high-income households increase the chances to belong to Class 2, while an increased number of owned cars or an increased household size increase the chances to fall in Class 1. Probability to belong to Class 3 remain relatively low compared to the other classes, which can be explained by the disutility of travelling in general within this class. The valuation of the trip characteristics in the different latent classes results in different accessibility patterns in these classes. Individuals in Class 1 perceive jobs to be accessible in the entire Randstad. People in Class 2 perceive only major cities in the Randstad to be accessible, caused by the increased transfer and thus waiting times in cities less connected by train transport. In Class 3 accessibility diminishes, causing only areas in Utrecht and thus in the proximity of the Merwedekanaalzone to be perceived as accessible.

To determine a base accessibility scenario for different population groups, socio-economic characteristics of a large number of households have been simulated based on the collected sample in car-free development areas. For walk-and-ride job accessibility, both with and without including other inhabitants that compete for the same job opportunities, senior adults perceive around half of the job accessible compared to family households. Households consisting of starters also perceive less accessible jobs compared to families, although only being around 30 percent lower. Low-income households perceive more than 50 percent additional jobs to be accessible compared to high-income households. Accessibility when considering a bicycle as a feeder mode drastically increases accessibility, perceiving between 50 and 80 percent more jobs as accessible when a bicycle is used as a feeder mode. This is in line with earlier results in the literature on walk-and-ride and bike-and ride accessibility. This is potentially due to the relative proximity of Utrecht CS in the Merwedekanaalzone. Being able to use a bicycle gives the opportunity to directly cycle to this train station, reducing waiting time and thus providing a large increase in perceived accessible jobs. This emphasises the need for dedicated cycling infrastructure not only in the Merwedekanaalzone but also in and between other neighbourhoods in Utrecht.

As the Merwedekanaalzone is not the exclusive location that is indicated as a potential location for a car-free development area, multiple other development areas have been analysed to indicate the suitability of the area to be developed as a car-free residential area. This provides indications on the suitability of the Merwedekanaalzone as a car-free development area compared to other development areas. Areas located closely to train stations provided better accessibility compared to locations in which a large number of job opportunities are nearby. This suggests that the transport component is more important than the number of job opportunities when determining job accessibility. However, job accessibility is not the only indicator for the suitability of a car-free development area, as other characteristics also influence this suitability.

3. What is the influence of various transport infrastructure measures on job accessibility of different population groups in the Merwedekanaalzone?

Proposed measures by the municipality differ in terms of the provided increase in job accessibility. Only developing the internal walking and cycling network within the Merwedekanaalzone already boost accessibility significantly, which could be due to the currently impenetrable character of the Merwedekanaalzone. Implementing bridges across the Merwedekanaal provide the largest increase in accessibility, with an increase of around 10 percent for every population group. The increase could be related to the possibility of walking to the train station of Vaartsche Rijn, instead of relying on a tram or bus connection to reach the train network.

Regarding tram measures, no clear difference can be seen between the two different routes that have been proposed. This indicates that most of the accessibility that is being provided by using tram transport is being provided by the track that is located directly on the western side of the Merwedekanaalzone. The similarity between the different tram tracks is however highly dependent on the exact origin location that is implemented in the used model. If an origin location is used that is situated on the southern edge of the Merwedekanaalzone, the tram track as proposed by experts from Mott MacDonald is clearly advantageous over the tram track that is proposed in documents provided by authorities in terms of job accessibility.

Upgrading train station Utrecht Lunetten to make it possible to provide an intercity service from this station does not affect accessibility, indicating that this train station is not used frequently in the current situation. As a conclusion, this measure could potentially only be beneficial in combination with the realisation of one of the proposed tram routes. This connects the tram network to the train network at this station, providing quick transfers to especially the eastern and southern parts of the Netherlands while also reducing the passenger load of Utrecht CS.

When a combination of measures is implemented, the highest increase in job accessibility is obtained. However, this increase is only marginally better compared to a situation in which bridges that cross the Merwedekanaal have been build. This suggests that the different measures provide an increase in accessibility in a different sphere of influence, but to some extend also provide better travel options to similar areas. Identical to only implementing a measure that extends the tram network, no differences are notable between the two tram routes when a combination of measures is implemented. This is however again also dependent on the exact origin within the Merwedekanaalzone, which illustrates the enormous scale of this car-free development area that needs to be taken into account.

What are the differences in socio-economic and travel characteristics in car-free development and what are the effects of transport infrastructure measures on job accessibility for different population groups?

Overall, it can be concluded that the inhabitants in a car-free area differ considerably from a traditional neighbourhood, both in terms of socio-economic as well as travel characteristics. Although the obtained sample is not completely collected within the Merwedekanaalzone nor are all the observed areas completely car-free, due to the results showing similarities with the literature it is expected that this sample approximates a general population in a car-free residential area. The characteristics in the observed areas show that especially due to the high car ownership and the attitude towards shared transport options, challenges arise whether the implementation of a car-free neighbourhood in the Merwedekanaalzone will be successful.

The used model is capable of evaluating accessibility in car-free development areas in Utrecht, while also making it possible to evaluate accessibility in other areas in the Netherlands with minor adjustments. Results show that especially families and low-income households perceive the highest number of jobs to be accessible, while senior adults and high-income household perceive less jobs to be accessible. Various evaluated measures all increase perceived job accessibility, although the magnitude of the increase in accessibility is different between measures. Population groups that perceive the least number of jobs to be accessible benefit the most from the measures, assisting in the goal of the municipality to provide healthy urban living for all its inhabitants.

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A. Survey set-up (NL)

Q1 Uw gegevens en antwoorden zullen beveiligd en geanonimiseerd worden bewaard en verwerkt, en zullen niet worden gebruikt voor doeleinden anders dan voor dit onderzoek. Gaat u hiermee akkoord?

○ Ja, ik geef toestemming om mijn ingevulde antwoorden te gebruiken voor dit onderzoek. (1)

○ Nee, ik geef geen toestemming. (2)

Skip To: End of Survey If Q1 = Nee, ik geef geen toestemming.

Page Break

Q2 In hoeverre bent u van plan om in de aankomende drie jaar te verhuizen naar een andere woning?

	Zeer waarschijnlijk (1)	Waarschijnlijk (2)	Enigszins waarschijnlijk (3)	Neutraal (4)	Enigszins onwaarschijnlijk (6)	Onwaarschijnlijk (7)	Zeer onwaarschijnlijk (8)
Verhuizen aankomende drie jaar (1)	○	○	○	○	○	○	○

Q3 Mocht u bij een eventuele verhuizing de kans krijgen om in een autovrije wijk te komen wonen die in uw benodigdheden voldoet, in hoeverre zou u geïnterreseerd zijn om dit te doen?

	Zeer geïnteresseerd (1)	Geïnteresseerd (2)	Enigszins geïnteresseerd (3)	Neutraal (4)	Enigszins ongeïnteresseerd (5)	Ongeïnteresseerd (6)	Zeer ongeïnteresseerd (7)
Interesse verhuizen naar autovrije wijk (1)	○	○	○	○	○	○	○

Q4 Wat is uw werksituatie

- ○ Zelfstandig ondernemer (1)
- ○ Werkzaam in loondienst (2)
- ○ Arbeidsongeschikt (3)
- ○ Werkloos/Werkzoekend/Bijstand (4)
- ○ Gepensioneerd of VUT (5)
- ○ Studerend/Schoolgaand (6)
- ○ Huisvrouw/Huisman/Anders (7)
- ○ Weet ik niet/Zeg ik liever niet (8)

Display This Question:

If Q4 != Werkzaam in loondienst

And Q4 != Zelfstandig ondernemer

Q5 Bedenk voor uzelf wat de meeste voorkomende reis is die u de afgelopen 12 maanden hebt gemaakt. Wat is het motief voor u om deze reis te maken?

- ○ School of studie (1)
- ○ Dagelijkse boodschappen (2)
- ○ Winkelen (3)
- ○ Bij iemand op bezoek gaan (4)
- ○ Uitgaan of een dagje weg (5)
- ○ Sporten (6)

Display This Question:

If Q4 = Zelfstandig ondernemer

Or Q4 = Werkzaam in loondienst

Q6a Wat is op dit moment de reistijd van uw woonlocatie naar uw werklocatie? Mocht u verschillende werkadressen hebben, neem dan de reistijd naar de meest voorkomende bestemming. Werkte u voor de Coronamaatregelen al vanuit huis, vul dan 0 minuten in.

	0	15	30	45	60	75	90	105	120	135	150
Reistijd in minuten (1)											

Display This Question:

If Q4 != Zelfstandig ondernemer

And Q4 != Werkzaam in loondienst

Q6b Wat is op dit moment de reistijd van uw woonlocatie naar deze bestemming?

	0	15	30	45	60	75	90	105	120	135	150
Reistijd in minuten (1)											

Display This Question:

If Q4 = Zelfstandig ondernemer

Or Q4 = Werkzaam in loondienst

Q7a Welk vervoersmiddel gebruikt u in de huidige situatie om op uw werkbestemming te komen? Indien u een combinatie van vervoermiddelen gebruikt (bijvoorbeeld fiets en openbaar vervoer), kruis dan het vervoermiddel waarin u het meeste tijd zou doorbrengen aan.

- ○ Auto (als bestuurder) (1)
- ○ Auto (als passagier) (2)
- ○ Motor (3)
- ○ Trein (7)
- ○ Bus/Tram/Metro (8)
- ○ Bromfiets/Scooter (9)
- ○ (Elektrische) fiets (10)
- ○ Lopen (11)
- ○ Anders, namelijk: (6)

Display This Question:

If Q4 != Zelfstandig ondernemer

And Q4 != Werkzaam in loondienst

Q7b Welk vervoersmiddel heeft u het meest gebruikt om op deze bestemming te komen? Indien u een combinatie van vervoermiddelen gebruikt (bijvoorbeeld fiets en openbaar vervoer), kruis dan het vervoermiddel waarin u het meeste tijd zou doorbrengen aan.

○ Auto (als bestuurder) (1)

○ Auto (als passagier) (2)

○ Motor (3)

○ Trein (7)

○ Bus/Tram/Metro (8)

○ Bromfiets/Scooter (9)

○ (Elektrische) fiets (10)

○ Lopen (11)

○ Anders, namelijk: (6)

Display This Question:

If Q4 = Zelfstandig ondernemer

Or Q4 = Werkzaam in loondienst

Q8a In hoeverre bent u tevreden met de huidige reistijd tussen uw werk en uw woning, alsook met het vervoermiddel waarmee u deze reis maakt?

	Zeer tevreden (1)	Tevreden (3)	Enigszins tevreden (4)	Neutraal (5)	Enigszins ontevreden (6)	Ontevreden (7)	Zeer ontevreden (8)
Tevredenheid huidige reistijd (2)	○	○	○	○	○	○	○
Tevredenheid huidig vervoermiddel (3)	○	○	○	○	○	○	○

Display This Question:

If Q4 != Zelfstandig ondernemer

And Q4 = Werkzaam in loondienst

Q8b In hoeverre bent u tevreden met de huidige reistijd naar uw meest voorkomende bestemming, alsook met het vervoermiddel waarmee u deze reis maakt?

	Zeer tevreden (1)	Tevreden (3)	Enigszins tevreden (4)	Neutraal (5)	Enigszins ontevreden (6)	Ontevreden (7)	Zeer ontevreden (8)
Tevredenheid huidige reistijd (2)	○	○	○	○	○	○	○
Tevredenheid huidig vervoermiddel (3)	○	○	○	○	○	○	○

Display This Question:

If Q7a = Trein

Or Q7a = Bus/Tram/Metro

Or Q7b = Trein

Or Q7b = Bus/Tram/Metro

Q9 U heeft aangegeven uw reis met behulp van het openbaar vervoer te maken. Wat is de reistijd van uw woning naar het OV-station dat u gebruikt om deze reis te maken?

	0	10	20	30	40	50	60
Reistijd in minuten ()							

Display This Question:

If Q7a = Trein

Or Q7a = Bus/Tram/Metro

Or Q7b = Trein

Or Q7b = Bus/Tram/Metro

Q10 Welk vervoermiddel gebruikt u voornamelijk om op het OV-station dat u gebruikt te geraken?

- ○ Auto (1)
- ○ Motor (3)
- ○ Bromfiets/Scooter (5)
- ○ (Elektrische) fiets (8)
- ○ Lopen (9)
- ○ Anders, namelijk: (6)

Display This Question:

If Q7a = Trein

Or Q7a = Bus/Tram/Metro

Or Q7b = Trein

Or Q7b = Bus/Tram/Metro

Q11 Hoe tevreden bent u met u de reistijd naar het OV-station dat u gebruikt, alsook met het vervoermiddel om op dit OV-station te geraken?

	Zeer tevreden (1)	Tevreden (3)	Enigszins tevreden (4)	Neutraal (5)	Enigszins ontevreden (6)	Ontevreden (7)	Zeer ontevreden (8)
Reistijd naar OV-station (2)	○	○	○	○	○	○	○
Vervoermiddel naar OV-station (3)	○	○	○	○	○	○	○

Display This Question:

If Q4 = Zelfstandig ondernemer

Or Q4 = Werkzaam in loondienst

Q12a Welk vervoermiddel zou u in een ideale situatie gebruiken om op uw werklocatie te komen, ervan uitgaande dat het vervoermiddel beschikbaar is om van uw woonlocatie op uw werklocatie te geraken? Dit is dus niet het daadwerkelijke vervoermiddel wat u gebruikt, maar het vervoermiddel wat u zou willen gebruiken. Indien u een combinatie van vervoermiddelen zou gebruiken (bijvoorbeeld fiets en openbaar vervoer), kruis dan het vervoermiddel waarin u het meeste tijd zou doorbrengen aan.

○ Auto (als bestuurder) (1)

○ Auto (als passagier) (2)

○ Motor (3)

○ Trein (7)

○ Bus/Tram/Metro (4)

○ Bromfiets/Scooter (5)

○ (Elektrische) fiets (8)

○ Lopen (9)

○ Anders, namelijk: (6)

Display This Question:

If Q4 != Zelfstandig ondernemer

And Q4 != Werkzaam in loondienst

Q12b Welk vervoermiddel zou u in een ideale situatie gebruiken om op uw meest voorkomende bestemming te komen, ervan uitgaande dat het vervoermiddel beschikbaar is deze reis te maken? Dit is dus niet het daadwerkelijke vervoermiddel wat u gebruikt, maar het vervoermiddel wat u zou willen gebruiken. Indien u een combinatie van vervoermiddelen zou gebruiken (bijvoorbeeld fiets en openbaar vervoer), kruis dan het vervoermiddel waarin u het meeste tijd zou doorbrengen aan.

○ Auto (als bestuurder) (1)

○ Auto (als passagier) (2)

○ Motor (3)

○ Trein (7)

○ Bus/Tram/Metro (4)

○ Bromfiets/Scooter (5)

○ (Elektrische) fiets (8)

○ Lopen (9)

○ Anders, namelijk: (6)

Q13 In de afgelopen 12 maanden, hoe vaak heeft u gemiddeld gebruik gemaakt van de volgende vervoermiddelen? Als gevolg van de maatregelen m.b.t. Corona is het mogelijk dat het aantal reizen is afgenomen. Indien dit het geval is, ga dan uit van een situatie voordat deze maatregelen van kracht gingen.

	4 of meer dagen per week (1)	1 tot 3 dagen per week (2)	1 tot 3 dagen per maand (3)	1 tot 2 dagen per kwartaal (4)	minder dan 1 dag per kwartaal, of nooit (5)
Eigen auto (1)	○	○	○	○	○
Deelauto (Greenwheels, Buurauto, MyWheels) (2)	○	○	○	○	○
Eigen (elektrische) fiets (3)	○	○	○	○	○
Deelfiets (OV-fiets, Donkey Republic) (4)	○	○	○	○	○
Eigen scooter of brommer (5)	○	○	○	○	○
Deelbrommer/Deelscooter (GO-Sharing, Felyx) (6)	○	○	○	○	○
Trein (7)	○	○	○	○	○
Bus/Tram/Metro (8)	○	○	○	○	○

Q14 Zijn de volgende vervoermiddelen beschikbaar binnen een straal van 15 minuten lopen van uw woning?

	Ja (1)	Nee (2)	Weet ik niet (3)
Deelauto (Greenwheels, Buurauto, MyWheels) (2)	○	○	○
Deelfiets (OV-fiets, Donkey Republic) (4)	○	○	○
Deelbrommer/Deelscooter (GO-Sharing, Felyx) (6)	○	○	○
Treinstation (7)	○	○	○
Bus-/Tram-/Metrostation (8)	○	○	○

Q15 Wat is uw houding tegenover de onderstaande vervoermiddelen? Voor het invullen van deze vraag hoeft u niet zelf gebruik te maken van het vervoermiddel. Het kan ook een vervoermiddel zijn dat u zelden of nooit gebruikt.

	Zeer positief (1)	Enigszins positief (3)	Positief (6)	Neutraal (7)	Enigszins negatief (8)	Negatief (9)	Zeer negatief (10)
Auto (alleen reizend) (2)	o	o	o	o	o	o	o
Auto (samen met bekenden reizend) (4)	o	o	o	o	o	o	o
Auto (samen met onbekenden reizen) (9)	o	o	o	o	o	o	o
Trein (11)	o	o	o	o	o	o	o
Bus/Tram/Metro (6)	o	o	o	o	o	o	o
Scooter/Brommer (7)	o	o	o	o	o	o	o
Motor (8)	o	o	o	o	o	o	o
Gewone fiets (12)	o	o	o	o	o	o	o
Elektrische fiets (14)	o	o	o	o	o	o	o

Q16 Hoeveel auto's zijn er aanwezig in uw huishouden?

- o 0 (1)
- o 1 (2)
- o 2 (3)
- o 3 of meer (4)
- o Geef ik liever niet aan (5)

Display This Question:

If Q16 != 0

Q17 Wat is de voornaamste reden voor u om een auto te bezitten?

- ○ Een auto geeft me meer mobiliteit dan andere vervoermiddelen. (1)
- ○ Een auto geeft me de minste moeite om op mijn bestemmingen te geraken. (2)
- ○ Een auto geeft me het meeste persoonlijke ruimte tijdens het reizen. (3)
- ○ Een auto geeft me een gevoel van vrijheid en/of een gevoel van controle. (4)
- ○ Een auto is voor mij het goedkoopst in gebruik. (5)
- ○ Anders, namelijk: (6)

Q18 In een autovrije of autoluwe wijk is het vaak niet mogelijk om uw auto bij uw woning te parkeren. Het is echter mogelijk dat u er voor kiest om toch een auto te bezitten terwijl u in een dergelijke wijk woont. Welke van de volgende mogelijkheden zou voor u het aantrekkelijkst zijn om uw auto te parkeren?

- ○ Ik zou mijn auto dichtbij mijn huis parkeren, wat de hoogste kosten met zich meebrengt. (1)
- ○ Ik zou mijn auto op een gemiddelde afstand van mijn huis parkeren, wat gemiddelde kosten met zich meebrengt. (2)
- ○ Ik zou mijn auto ver weg van mijn huis parkeren, wat de laagste kosten met zich meebrengt. (3)

Q19 Is een van de volgende stellingen op u van toepassing?

	Ja (1)	Soms (2)	Nee (3)
Ik reis met een rolstoel (1)	○	○	○
Ik reis met een rollator (2)	○	○	○
Ik reis met een scootmobiel (3)	○	○	○
Ik reis met een hulphond (4)	○	○	○
Ik kan maximaal 10 minuten lopen (5)	○	○	○
Ik heb hulp nodig om in een bus, tram, trein of auto in- of uit te stappen (6)	○	○	○

Q20 In hoeverre bent u het eens met de volgende stellingen over het gebruik van verschillende vervoermiddelen? Deze stellingen gaan over het in staat zijn om iets uit te voeren. U hoeft bijvoorbeeld geen auto te bezitten om een auto te kunnen besturen.

	Helemaal mee oneens (1)	Mee oneens (2)	Niet mee eens, noch mee oneens (3)	Mee eens (4)	Helemaal mee eens (5)
Ik kan zelfstandig reizen met het OV (bus, tram, metro, trein) (1)	○	○	○	○	○
Ik ervaar genoeg veiligheid in het OV om op elk moment van de dag hiervan gebruik te willen maken. (2)	○	○	○	○	○
Ik kan zelfstandig reizen met de auto (3)	○	○	○	○	○
Ik kan zelfstandig reizen met de (elektrische) fiets, scooter en/of brommer (6)	○	○	○	○	○
Ik ervaar genoeg veiligheid om in een stedelijke omgeving gebruik te maken van een (elektrische) fiets, scooter en/of brommer (4)	○	○	○	○	○
Ik kan nieuwe apps op mijn telefoon installeren (5)	○	○	○	○	○
Ik kan een reisroute plannen met behulp van online routeplanners (zoals Google Maps of 9292ov) (7)	○	○	○	○	○

C1I1 In de volgende sectie zullen er vijf verschillende situaties geschetst worden, waarin aspecten van het transportnetwerk in Utrecht zijn beschreven. Twee overzichten van autovrije wijken worden beschreven, welke zullen verschillen in de aspecten van het transportnetwerk. Bij elke vraag kunt aangeven welke van de twee wijken uw voorkeur zou hebben.

De wijken zullen verschillen in de volgende aspecten:
1. **Kosten deelauto**: De kosten voor het gebruik van een deelauto in de wijk, waarin u de deelauto voor 5 uur in uw bezit heeft en een totale afstand van 50 kilometer aflegt.
2. **Reistijd in openbaar vervoer**: De reistijd tussen het dichtsbijzijnde OV-station en uw werk, welke u aflegt met het openbaar vervoer.
3. **Looptijd naar OV-station**: De tijd die het u kost om naar het dichtstbijzijnde OV-station te lopen.
4. **Wachttijd OV of deelautostation**: De gemiddelde tijd die u moet wachten op het station voordat u kunt instappen in de bus/tram/metro/trein of voordat er een deelauto beschikbaar is om te gebruiken.

C1I2 In de volgende sectie zullen er vijf verschillende situaties geschetst worden, waarin aspecten van het transportnetwerk in Utrecht zijn beschreven. Twee overzichten van autovrije wijken worden beschreven, welke zullen verschillen in de aspecten van het transportnetwerk. Bij elke vraag kunt aangeven welke van de twee wijken uw voorkeur zou hebben.

De wijken zullen verschillen in de volgende aspecten:
1. **Kosten deelauto**: De kosten voor het gebruik van een deelauto in de wijk, waarin u de deelauto voor 5 uur in uw bezit heeft en een totale afstand van 50 kilometer aflegt.
2. **Reistijd in openbaar vervoer**: De reistijd tussen het dichtsbijzijnde OV-station en uw meestvoorkomende bestemming, welke u aflegt met het openbaar vervoer.
3. **Looptijd naar OV-station**: De tijd die het u kost om naar het dichtstbijzijnde OV-station te lopen.
4. **Wachttijd OV of deelautostation**: De gemiddelde tijd die u moet wachten op het station voordat u kunt instappen in de bus/tram/metro/trein of voordat er een deelauto beschikbaar is om te gebruiken.

C1Q1 Uitgaande van de volgende aspecten, welke autovrije wijk zou uw voorkeur hebben?

	Wijk A	Wijk B
Kosten deelauto	€15	€35
Reistijd in openbaar vervoer	20% minder dan origineel	Hetzelfde als origineel
Looptijd naar OV-station	18 minuten	12 minuten
Wachttijd OV- of deelautostation	Gemiddeld 10 minuten wachten	Gemiddeld 15 minuten wachten

	Wijk A (1)	Wijk B (2)	Geen voorkeur (3)
Keuze: (1)	○	○	○

Display This Question:

If Q16 != 0

And C1Q1 != Keuze: [Geen voorkeur]

C1O1 Uitgaande van de door u aangegeven voorkeurswijk en de bijbehorende aspecten zoals beschreven bij de vorige vraag, hoeveel auto's zou u weg doen in deze situatie?

○ 0 auto's (1)

○ 1 auto (2)

Q16 = 2

Or Q16 = 3 of meer

Or Q16 = Geef ik liever niet aan

○ 2 auto's (3)

Q16 = 3 of meer

Or Q16 = Geef ik liever niet aan

○ 3 of meer auto's (4)

C1Q2 Uitgaande van de volgende aspecten, welke autovrije wijk zou uw voorkeur hebben?

	Wijk A	Wijk B
Kosten deelauto	€25	€15
Reistijd in openbaar vervoer	20% minder dan origineel	20% meer dan origineel
Looptijd naar OV-station	6 minuten	12 minuten
Wachttijd OV- of deelautostation	Gemiddeld 10 minuten wachten	Gemiddeld 5 minuten wachten

	Wijk A (1)	Wijk B (2)	Geen voorkeur (3)
Keuze: (1)	○	○	○

Display This Question:

If Q16 != 0

And C1Q2 != Keuze: [Geen voorkeur]

C1O2 Uitgaande van de door u aangegeven voorkeurswijk en de bijbehorende aspecten zoals beschreven bij de vorige vraag, hoeveel auto's zou u weg doen in deze situatie?

- ○ 0 auto's (1)
- ○ 1 auto (2)

Q16 = 2

Or Q16 = 3 of meer

Or Q16 = Geef ik liever niet aan

- ○ 2 auto's (3)

Q16 = 3 of meer

Or Q16 = Geef ik liever niet aan

- ○ 3 of meer auto's (4)

C1Q3 Uitgaande van de volgende aspecten, welke autovrije wijk zou uw voorkeur hebben?

	Wijk A	Wijk B
Kosten deelauto	€25	€15
Reistijd in openbaar vervoer	20% meer dan origineel	Hetzelfde als origineel
Looptijd naar OV-station	6 minuten	12 minuten
Wachttijd OV- of deelautostation	Gemiddeld 5 minuten wachten	Gemiddeld 15 minuten wachten

	Wijk A (1)	Wijk B (2)	Geen voorkeur (3)
Keuze: (1)	○	○	○

Display This Question:

If Q16 != 0

And C1Q3 != Keuze: [Geen voorkeur]

C1O3 Uitgaande van de door u aangegeven voorkeurswijk en de bijbehorende aspecten zoals beschreven bij de vorige vraag, hoeveel auto's zou u weg doen in deze situatie?

○ 0 auto's (1)

○ 1 auto (2)

Q16 = 2

Or Q16 = 3 of meer

Or Q16 = Geef ik liever niet aan

○ 2 auto's (3)

Q16 = 3 of meer

Or Q16 = Geef ik liever niet aan

○ 3 of meer auto's (4)

C1Q4 Uitgaande van de volgende aspecten, welke autovrije wijk zou uw voorkeur hebben?

	Wijk A	Wijk B
Kosten deelauto	€35	€25
Reistijd in openbaar vervoer	20% minder dan origineel	Hetzelfde als origineel
Looptijd naar OV-station	6 minuten	18 minuten
Wachttijd OV- of deelautostation	Gemiddeld 10 minuten wachten	Gemiddeld 5 minuten wachten

	Wijk A (1)	Wijk B (2)	Geen voorkeur (3)
Keuze: (1)	○	○	○

Display This Question:

If Q16 != 0

And C1Q4 != Keuze: [Geen voorkeur]

C1O4 Uitgaande van de door u aangegeven voorkeurswijk en de bijbehorende aspecten zoals beschreven bij de vorige vraag, hoeveel auto's zou u weg doen in deze situatie?

○ 0 auto's (1)

○ 1 auto (2)

Q16 = 2

Or Q16 = 3 of meer

Or Q16 = Geef ik liever niet aan

○ 2 auto's (3)

Q16 = 3 of meer

Or Q16 = Geef ik liever niet aan

○ 3 of meer auto's (4)

C1Q5 Uitgaande van de volgende aspecten, welke autovrije wijk zou uw voorkeur hebben?

	Wijk A	Wijk B
Kosten deelauto	€15	€25
Reistijd in openbaar vervoer	20% meer dan origineel	20% minder dan origineel
Looptijd naar OV-station	12 minuten	18 minuten
Wachttijd OV- of deelautostation	Gemiddeld 15 minuten wachten	Gemiddeld 10 minuten wachten

	Wijk A (1)	Wijk B (2)	Geen voorkeur (3)
Keuze: (1)	○	○	○

Display This Question:

If Q16 != 0

And C1Q5 != Keuze: [Geen voorkeur]

C1O5 Uitgaande van de door u aangegeven voorkeurswijk en de bijbehorende aspecten zoals beschreven bij de vorige vraag, hoeveel auto's zou u weg doen in deze situatie?

- ○ 0 auto's (1)
- ○ 1 auto (2)

Q16 = 2

Or Q16 = 3 of meer

Or Q16 = Geef ik liever niet aan

- ○ 2 auto's (3)

Q16 = 3 of meer

Or Q16 = Geef ik liever niet aan

- ○ 3 of meer auto's (4)

Q21 Wat is uw leeftijd?

- Leeftijd: (9)
- Geef ik liever niet aan (6)

Q22 Wat is uw geslacht?

- Man (1)
- Vrouw (2)
- Anders/Geef ik liever niet aan (4)

Q23 Hoeveel personen bevinden er zich in uw huishouden?

- 1 persoon (1)
- 2 personen (2)
- 3 personen (3)
- 4 personen (4)
- 5 personen (5)
- Meer dan 5 personen (6)

Q24 Wat is de samenstelling van uw huishouden?

- Alleenstaand (1)
- Eenoudergezin (2)
- Paar zonder kinderen (3)
- Paar met kinderen (4)
- Studentenhuis/samenwonend met kamergenoten (5)

Q25 Wat is het bruto jaarinkomen van uw huishouden?

- ○ Minimum (< €12.000) (1)
- ○ Beneden modaal (€12.500 - €26.200) (2)
- ○ Modaal (€26.200 - €38.800) (3)
- ○ 1-2x Modaal (€38.800 - €65.000) (4)
- ○ 2x Modaal €65.000 - €77.500) (5)
- ○ Meer dan 2x modaal (> €77.500) (6)
- ○ Weet ik niet/Geef ik liever niet aan (7)

Q26 Bent u in het bezit van een autorijbewijs (Rijbewijs B)?

- ○ Ja (1)
- ○ Nee (2)

Q27 Wat is uw postcode?

- ○ Postcode: (1)
- ○ Geef ik liever niet aan (2)

Display This Question:

If Q4 = Zelfstandig ondernemer

Or Q4 = Werkzaam in loondienst

Q28 Wat zijn normaliter gezien uw standaard werktijden? Indien deze variabel zijn kunt u deze vraag leeg laten.

- ○ Begintijd (1)
- ○ Eindtijd (2)

B. Survey set-up (EN)

Q1 Your answers and personal details will be stored securely, will only be used anonymously for this research and will not be shared to third parties. Do you agree that your answers will be used as part of this research?

- ○ Yes, I give permission to store my personal information and analyse my answers within the remainder of this research. (1)
- ○ No, I do not give permission. (2)

Skip To: End of Survey If Q1 = No, I do not give permission.

Page Break

Q2 What is the likelihood for you to relocate within the next five years?In hoeverre bent u van plan om in de aankomende drie jaar te verhuizen naar een andere woning?

	Very likely (1)	Likely (2)	Somewhat likely (3)	Neutral (4)	Somewhat unlikely (6)	Unlikely (7)	Very Unlikely (8)
Likelihood to relocate (1)	○	○	○	○	○	○	○

Q3 Given that the area satisfies your needs, how interested would you be to move to a car-free development area?

	Very interested (1)	Interested (2)	Somewhat interested (3)	Neutral (4)	Somewhat uninterested (5)	Uninterested (6)	Very Uninterested (7)
Moving to car-free area (1)	○	○	○	○	○	○	○

Q4 What is your current working situation?

○ Self-employed (1)

○ Employed on payroll (2)

○ Incapacitated (3)

○ Unemployed/Looking for job (4)

○ Retired (5)

○ Student (6)

○ Housewife/Husband (7)

○ I don’t know/I rather don’t tell (8)

Display This Question:

If Q4 != Employed on payroll

Or Q4 != Self-employed

Q5 Consider to most frequently occurring trip in the last 12 months. What is the motive for you to make this trip?

○ School or study (1)

○ Daily groceries (2)

○ Shopping (3)

○ Visiting someone (4)

○ Leisure (5)

○ Sports (6)

Display This Question:

If Q4 = Employed on payroll

Or Q4 = Self-employed

Q6a What is your current commuting travel time? In case you have multiple working places, please use the place most frequently visited. If you currently work from home due to restrictions regarding Corona, please consider your travel patterns before these restrictions occurred.

	0	15	30	45	60	75	90	105	120	135	150
Travel time in minutes (1)											

Display This Question:

If Q4 != Employed on payroll

And Q4 != Self-employed

Q6b What is your current travel time from your residence to this destination?

	0	15	30	45	60	75	90	105	120	135	150
Travel time in minutes (1)											

Display This Question:

If Q4 = Self-employed

Or Q4 = Employed on payroll

Q7a Which mode of transport do you currently use to reach your job location? If you are using a combination of transport modes, please answer with the transport mode you cover the largest distance with.

- ○ Car (as driver) (1)
- ○ Car (as a passenger) (2)
- ○ Motor (3)
- ○ Train (7)
- ○ Bus/Tram/Metro (8)
- ○ Scooter/Moped (9)
- ○ (Electric) Bike (10)
- ○ On Foot (11)
- ○ Other, being: (6)

Display This Question:

If Q4 != Self-employed

And Q4 != Employed on payroll

Q7b Which mode of transport do you currently use to reach this destination? If you are using a combination of transport modes, please answer with the transport mode you cover the largest distance with.

- ○ Car (as driver) (1)
- ○ Car (as a passenger) (2)
- ○ Motor (3)
- ○ Train (7)
- ○ Bus/Tram/Metro (8)
- ○ Scooter/Moped (9)
- ○ (Electric) Bike (10)
- ○ On foot (11)
- ○ Other, being: (6)

Display This Question:

If Q4 = Self-employed

Or Q4 = Employed on payroll

Q8a How satisfied are you with your current commuting time and commuting mode of transport?

	Very Satisfied (1)	Satisfied (3)	Somewhat satisfied (4)	Neutral (5)	Somewhat dissatisfied (6)	Dissatisfied (7)	Very dissatisfied (8)
Satisfaction current commuting time (2)	○	○	○	○	○	○	○
Satisfaction current commuting transport mode (3)	○	○	○	○	○	○	○

Display This Question:

If Q4 != Self-employed

And Q4 = Employed on payroll

Q8b 6. How satisfied are you with your current travel time and mode of transport to this location?

	Very Satisfied (1)	Satisfied (3)	Somewhat satisfied (4)	Neutral (5)	Somewhat dissatisfied (6)	Dissatisfied (7)	Very dissatisfied (8)
Satisfaction current commuting time (2)	○	○	○	○	○	○	○
Satisfaction current commuting transport mode (3)	○	○	○	○	○	○	○

Display This Question:

If Q7a = Train

Or Q7a = Bus/Tram/Metro

Or Q7b = Train

Or Q7b = Bus/Tram/Metro

Q9 You responded to mostly use a form of public transport to reach your job location. What is your travel time towards the public transport station that you use to make this trip?

	0	10	20	30	40	50	60
Travel time in minutes (1)							

Display This Question:

If Q7a = Train

Or Q7a = Bus/Tram/Metro

Or Q7b = Traein

Or Q7b = Bus/Tram/Metro

Q10 Which mode of transport do you mainly use to reach this public transport station?

- Car (1)
- Motor (3)
- Scooter/Moped (5)
- (Electric) bike (8)
- On foot (9)
- Other, being: (6)

Display This Question:

If Q7a = Train

Or Q7a = Bus/Tram/Metro

Or Q7b = Train

Or Q7b = Bus/Tram/Metro

Q11 How satisfied are you with your current travel time and transport mode to the public transport station that you use??

	Very Satisfied (1)	Satisfied (3)	Somewhat satisfied (4)	Neutral (5)	Somewhat dissatisfied (6)	Dissatisfied (7)	Very dissatisfied (8)
Travel time to PT station (2)	○	○	○	○	○	○	○
Travel mode to PT station (3)	○	○	○	○	○	○	○

Display This Question:

If Q4 = Self-employed

Or Q4 = Employed on payroll

Q12a Which mode of transport would you prefer the most when going to your job location? Note that this is not the actual transport mode but the transport mode that you would like to use. If your preference is a combination of transport modes, please answer with the transport mode you would cover the largest distance with.

- Car (as driver) (1)
- Car (as a passenger) (2)
- Motor (3)
- Train (7)
- Bus/Tram/Metro (8)
- Scooter/Moped (9)
- (Electric) Bike (10)
- On foot (11)
- Other, being: (6)

Display This Question:

If Q4 != Self-employed

And Q4 != Employed on payroll

Q12b Which mode of transport would you prefer the most when going the location of this activity? Note that this is not the actual transport mode but the transport mode that you would like to use. If your preference is a combination of transport modes, please answer with the transport mode you would cover the largest distance with.

- Car (as driver) (1)
- Car (as a passenger) (2)
- Motor (3)
- Train (7)
- Bus/Tram/Metro (8)
- Scooter/Moped (9)
- (Electric) Bike (10)
- On foot (11)
- Other, being: (6)

Q13 Within the past 12 months, how often have you on average used one of the following transport modes to reach your job location? Please consider a situation before Corona regulations applied to you.

	4 days or more per week (1)	1 to 3 days per week (2)	1 to 3 days per month (3)	1 to 2 days per quarter of a year (4)	Less than once per quarter of a year, or never (5)
Private car (1)	○	○	○	○	○
Shared car (e.g. Greenwheels, Buurauto, MyWheels) (2)	○	○	○	○	○
Private (e)-bike (3)	○	○	○	○	○
Shared bike (e.g. OV-fiets, Donkey Republic) (4)	○	○	○	○	○
Private scooter/moped (5)	○	○	○	○	○
Shared scooter/moped (e.g. GO-Sharing, Felyx) (6)	○	○	○	○	○
Train (7)	○	○	○	○	○
Bus/Tram/Metro (8)	○	○	○	○	○

Q14 Are the following transport modes available within a 15-minute walk of your residence?

	Yes (1)	No (2)	I don't know (3)
Shared car (e.g. Greenwheels, Buurauto, MyWheels) (2)	○	○	○
Shared bike (e.g. OV-fiets, Donkey Republic) (4)	○	○	○
Shared scooter/moped (e.g. GO-Sharing, Felyx) (6)	○	○	○
Train stop (7)	○	○	○
Bus/tram/metro stop (8)	○	○	○

Q15 What is your attitude towards the following transport modes? You do not have to make use of this transport mode yourself, it is possible that you barely or never use this transport mode.

	Very positive(1)	Somewhat positive (3)	Positive (6)	Neutral (7)	Somewhat negative (8)	Negative (9)	Very negative(10)
Car (travelling alone) (2)	○	○	○	○	○	○	○
Car (traveling with acquaintances) (4)	○	○	○	○	○	○	○
Car (travelling with strangers) (9)	○	○	○	○	○	○	○
Train (11)	○	○	○	○	○	○	○
Bus/Tram/Metro (6)	○	○	○	○	○	○	○
Scooter/Moped (7)	○	○	○	○	○	○	○
Motor (8)	○	○	○	○	○	○	○
Regular bike (12)	○	○	○	○	○	○	○
Electric bike (14)	○	○	○	○	○	○	○

Q16 How many cars are present within your household?

○ 0 (1)

○ 1 (2)

○ 2 (3)

○ 3 or more (4)

○ I rather don’t tell (5)

Display This Question:

If Q16 != 0

Q17 What is the main reason for you to own a car?

- ○ A private car provides better mobility than all other transport modes. (1)
- ○ A private car grants me the least amount of effort to reach my destinations. (2)
- ○ A private car gives me the most amount of personal space when travelling. (3)
- ○ A private car gives me a sense of control or a sense of freedom. (4)
- ○ A private car has the least monetary costs involved. (5)
- ○ Other, being: (6)

Q18 Within most car-free development areas it is not possible to park your car directly next to your residence. However, it is possible that you decide to own a car when you live in a car-free development area. Considering the following options to park your private car, which option would be most attractive to you?

- ○ I would make use of one of the parking garages at the edge of the car-free neighbourhood. (Highest price, smallest distance to residence) (1)
- ○ I would park my vehicle in an adjacent neighbourhood. (Average price, average distance to residence) (2)
- ○ I would park my vehicle in a Park and Ride garage at the outskirt of the city. (Lowest price, largest distance to residence) (3)

Q19 Is one of the following statements applicable to you?

	Yes (1)	Sometimes (2)	No (3)
I travel using a wheelchair (1)	○	○	○
I travel using a rollator (2)	○	○	○
I travel using a mobility scooter (3)	○	○	○
I travel with an assistance dog (4)	○	○	○
I can walk at maximum 10 minutes (5)	○	○	○
I need assistance getting in and out of a bus, tram, train or car (6)	○	○	○

Q20 To what extend do you agree or disagree with the following statements? Note that these statements are about your individual possibility, if for example you do not own a car it is still possible for you to be capable to travel independently using a car.

	Totally disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Totally agree (5)
I can travel independently using public transport (Bus, tram, metro, train) (1)	○	○	○	○	○
I feel safe enough in terms of security to use public transport at any time of the day (2)	○	○	○	○	○
I can travel independently using a car (3)	○	○	○	○	○
I can travel independently using a bike, e-bike, scooter and/or moped (6)	○	○	○	○	○
I feel safe enough in terms of traffic safety to use a bike or e-bike within an urban environment (4)	○	○	○	○	○
I am capable of installing a new application on my phone (5)	○	○	○	○	○
I am capable of planning a travel route using an online trip planner (e.g. Google Maps, 9292) (7)	○	○	○	○	○

C1I1 Within the following section, five different situations will be drafted in which aspects of a car-free development area in Utrecht have been described. The two overviews of the car-free development area will consist of different characteristics, that change at every situation. At every question, you can make a choice between two possibilities. Taking into account the different aspects that are present, you can decide which option is the most attractive to you

The neighbourhoods will differ in terms of the following characteristics:
1. **Costs shared car**: Costs for using a shared car in your neighbourhood.
2. **Travel time in public transport:** Travel time between the closest PT station and your job location, using a form of public transport.
3. **Walking time to PT station:** Time it takes to walk to the PT station that you use.
4. **Waiting time on station**: Average time you have to wait at the station before you can board a public transport mode or before a shared car becomes available.

C1I2 Within the following section, five different situations will be drafted in which aspects of a car-free development area in Utrecht have been described. The two overviews of the car-free development area will consist of different characteristics, that change at every situation. At every question, you can make a choice between two possibilities. Taking into account the different aspects that are present, you can decide which option is the most attractive to you

The neighbourhoods will differ in terms of the following characteristics:
1. **Costs shared car**: Costs for using a shared car in your neighbourhood.
2. **Travel time in public transport:** Travel time between the closest PT station and your most frequent destination location, using a form of public transport.
3. **Walking time to PT station:** Time it takes to walk to the PT station that you use.
4. **Waiting time on station**: Average time you have to wait at the station before you can board a public transport mode or before a shared car becomes available.

C1Q1 Considering the following aspects, which car-free development area would have your preference?

	Wijk A	Wijk B
Kosten deelauto	€15	€35
Reistijd in openbaar vervoer	20% minder dan origineel	Hetzelfde als origineel
Looptijd naar OV-station	18 minuten	12 minuten
Wachttijd OV- of deelautostation	Gemiddeld 10 minuten wachten	Gemiddeld 15 minuten wachten

	Neighbourhood A (1)	Neighbourhood B (2)	Neither of the two (3)
Choice: (1)	○	○	○

Display This Question:

If Q16 != 0

And C1Q1 != Choice: [Neither of the two]

C1O1 Given the aspects of the neighbourhood you choose, what would be the likelihood of you giving up car ownership?

○ 0 cars (1)

○ 1 car (2)

Q16 = 2

Or Q16 = 3 or more

Or Q16 = I rather don't tell

○ 2 car (3)

Q16 = 3 or more

Or Q16 = I rather don't tell

○ 3 or more cars (4)

C1Q2 Considering the following aspects, which car-free development area would have your preference?

	Wijk A	Wijk B
Kosten deelauto	€25	€15
Reistijd in openbaar vervoer	20% minder dan origineel	20% meer dan origineel
Looptijd naar OV-station	6 minuten	12 minuten
Wachttijd OV- of deelautostation	Gemiddeld 10 minuten wachten	Gemiddeld 5 minuten wachten

	Neighbourhood A (1)	Neighbourhood B (2)	Neither of the two (3)
Choice: (1)	○	○	○

Display This Question:

If Q16 != 0

And C1Q2 != Choice: [Neither of the two]

C1O2 Given the aspects of the neighbourhood you choose, what would be the likelihood of you giving up car ownership?

- ○ 0 cars (1)
- ○ 1 car (2)

Q16 = 2

Or Q16 = 3 or more

Or Q16 = I rather don't tell

- ○ 2 car (3)

Q16 = 3 or more

Or Q16 = I rather don't tell

- ○ 3 or more cars (4)

C1Q3 Considering the following aspects, which car-free development area would have your preference?

	Wijk A	Wijk B
Kosten deelauto	€25	€15
Reistijd in openbaar vervoer	20% meer dan origineel	Hetzelfde als origineel
Looptijd naar OV-station	6 minuten	12 minuten
Wachttijd OV- of deelautostation	Gemiddeld 5 minuten wachten	Gemiddeld 15 minuten wachten

	Neighbourhood A (1)	Neighbourhood B (2)	Neither of the two (3)
Choice: (1)	○	○	○

Display This Question:

If Q16 != 0

And C1Q3 != Choice: [Neither of the two]

C1O3 Given the aspects of the neighbourhood you choose, what would be the likelihood of you giving up car ownership?

- ○ 0 cars (1)
- ○ 1 car (2)

Q16 = 2

Or Q16 = 3 or more

Or Q16 = I rather don't tell

- ○ 2 car (3)

Q16 = 3 or more

Or Q16 = I rather don't tell

- ○ 3 or more cars (4)

C1Q4 Considering the following aspects, which car-free development area would have your preference?

	Wijk A	Wijk B
Kosten deelauto	€35	€25
Reistijd in openbaar vervoer	20% minder dan origineel	Hetzelfde als origineel
Looptijd naar OV-station	6 minuten	18 minuten
Wachttijd OV- of deelautostation	Gemiddeld 10 minuten wachten	Gemiddeld 5 minuten wachten

	Neighbourhood A (1)	Neighbourhood B (2)	Neither of the two (3)
Choice: (1)	○	○	○

Display This Question:

If Q16 != 0

And C1Q4 != Choice: [Neither of the two]

C1O4 Given the aspects of the neighbourhood you choose, what would be the likelihood of you giving up car ownership?

○ 0 cars (1)

○ 1 car (2)

Q16 = 2

Or Q16 = 3 or more

Or Q16 = I rather don't tell

○ 2 car (3)

Q16 = 3 or more

Or Q16 = I rather don't tell

○ 3 or more cars (4)

C1Q5 Considering the following aspects, which car-free development area would have your preference?

	Wijk A	Wijk B
Kosten deelauto	€15	€25
Reistijd in openbaar vervoer	20% meer dan origineel	20% minder dan origineel
Looptijd naar OV-station	12 minuten	18 minuten
Wachttijd OV- of deelautostation	Gemiddeld 15 minuten wachten	Gemiddeld 10 minuten wachten

	Neighbourhood A (1)	Neighbourhood B (2)	Neither of the two (3)
Choice: (1)	○	○	○

Display This Question:

If Q16 != 0

And C1Q5 != Choice: [Neither of the two]

C1O5 Given the aspects of the neighbourhood you choose, what would be the likelihood of you giving up car ownership?

○ 0 cars (1)

○ 1 car (2)

Q16 = 2

Or Q16 = 3 or more

Or Q16 = I rather don't tell

○ 2 car (3)

Q16 = 3 or more

Or Q16 = I rather don't tell

○ 3 or more cars (4)

Q21 What is your age?

- Age: (9)
- I rather don't tell (6)

Q22 What is your gender?

- Male (1)
- Female (2)
- Other/I rather don't tell (4)

Q23 Of how many persons consists your household?

- 1 person (1)
- 2 persons (2)
- 3 persons (3)
- 4 persons (4)
- 5 persons (5)
- More than 5 persons (6)

Q24 What is the composition of your household?

- Single person (1)
- Single parent family (2)
- Pair without children (3)
- Pair with children (4)
- Student residence/cohabitation with roommate(s) (5)

Q25 What is the gross yearly income of your household?

- ○ Minimal (< €12.500) (1)
- ○ Below average (€12.500 - €26.200) (2)
- ○ Average (€26.200 - €38.800) (3)
- ○ 1-2x Average (€38.800 - €65.000) (4)
- ○ 2x Average €65.000 - €77.500) (5)
- ○ More than 2 times average (> €77.500) (6)
- ○ I don't know/I rather don't tell (7)

Q26 Do you have a driver's license for a car (License B)?

- ○ yes (1)
- ○ No (2)

Q27 What is your postal code?

- ○ Postal code: (1)
- ○ I rather don't tell (2)

Display This Question:

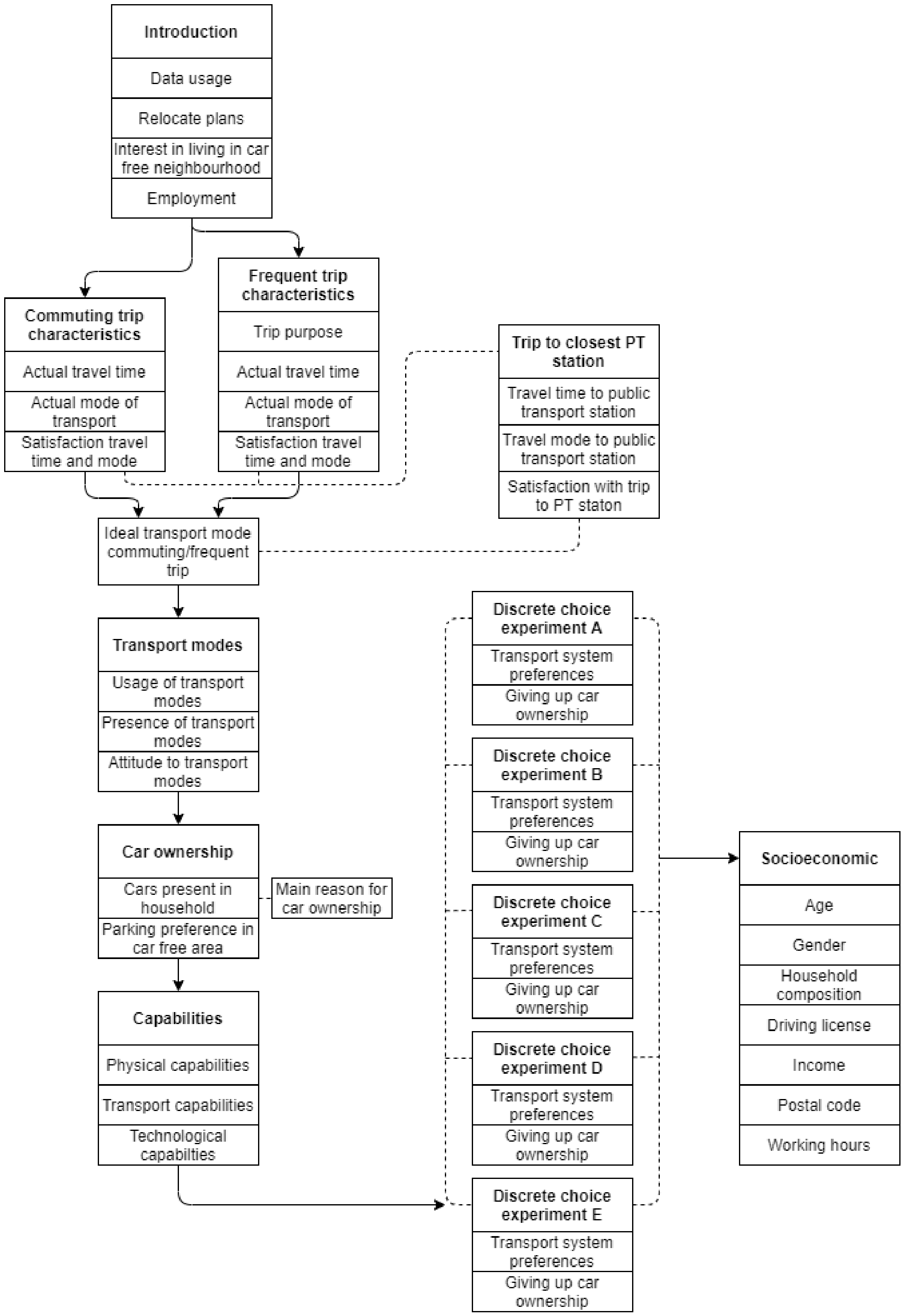
If Q4 = Self-employed

Or Q4 = Employed on payroll

Q28 What are normally the times you leave from and return to home before and after work?

- ○ Starting time (1)
- ○ Ending time (2)

C. Survey path



D. Choice set discrete choice experiment

Survey	Choice Set	Totale reiskosten deelauto	Reistijd	Looptijd naar station	Gemiddelde wachttijd OV/SC
1	1	€ 15	20% minder dan origineel	18 minuten	Gemiddeld 10 minuten wachten
1	1	€ 35	Hetzelfde als origineel	12 minuten	Gemiddeld 15 minuten wachten
1	2	€ 25	20% minder dan origineel	6 minuten	Gemiddeld 10 minuten wachten
1	2	€ 15	20% meer dan origineel	12 minuten	Gemiddeld 5 minuten wachten
1	3	€ 25	20% meer dan origineel	6 minuten	Gemiddeld 5 minuten wachten
1	3	€ 15	Hetzelfde als origineel	12 minuten	Gemiddeld 15 minuten wachten
1	4	€ 35	20% minder dan origineel	6 minuten	Gemiddeld 10 minuten wachten
1	4	€ 25	Hetzelfde als origineel	18 minuten	Gemiddeld 5 minuten wachten
1	5	€ 15	20% meer dan origineel	12 minuten	Gemiddeld 15 minuten wachten
1	5	€ 25	20% minder dan origineel	18 minuten	Gemiddeld 10 minuten wachten
2	6	€ 25	Hetzelfde als origineel	6 minuten	Gemiddeld 10 minuten wachten
2	6	€ 35	20% minder dan origineel	12 minuten	Gemiddeld 15 minuten wachten
2	7	€ 35	Hetzelfde als origineel	6 minuten	Gemiddeld 10 minuten wachten
2	7	€ 25	20% meer dan origineel	18 minuten	Gemiddeld 15 minuten wachten
2	8	€ 25	20% minder dan origineel	12 minuten	Gemiddeld 10 minuten wachten
2	8	€ 15	20% meer dan origineel	6 minuten	Gemiddeld 5 minuten wachten
2	9	€ 35	20% minder dan origineel	18 minuten	Gemiddeld 5 minuten wachten
2	9	€ 25	Hetzelfde als origineel	12 minuten	Gemiddeld 10 minuten wachten
2	10	€ 25	20% meer dan origineel	6 minuten	Gemiddeld 15 minuten wachten
2	10	€ 35	20% minder dan origineel	12 minuten	Gemiddeld 10 minuten wachten
3	11	€ 25	20% minder dan origineel	12 minuten	Gemiddeld 5 minuten wachten
3	11	€ 15	20% meer dan origineel	18 minuten	Gemiddeld 10 minuten wachten
3	12	€ 25	Hetzelfde als origineel	18 minuten	Gemiddeld 15 minuten wachten
3	12	€ 15	20% meer dan origineel	12 minuten	Gemiddeld 10 minuten wachten
3	13	€ 15	20% meer dan origineel	12 minuten	Gemiddeld 10 minuten wachten
3	13	€ 25	Hetzelfde als origineel	6 minuten	Gemiddeld 5 minuten wachten
3	14	€ 25	20% minder dan origineel	12 minuten	Gemiddeld 15 minuten wachten
3	14	€ 35	Hetzelfde als origineel	18 minuten	Gemiddeld 10 minuten wachten
3	15	€ 25	20% meer dan origineel	12 minuten	Gemiddeld 10 minuten wachten
3	15	€ 35	20% minder dan origineel	6 minuten	Gemiddeld 15 minuten wachten
4	16	€ 15	20% meer dan origineel	18 minuten	Gemiddeld 5 minuten wachten
4	16	€ 35	Hetzelfde als origineel	6 minuten	Gemiddeld 15 minuten wachten
4	17	€ 25	20% meer dan origineel	6 minuten	Gemiddeld 10 minuten wachten
4	17	€ 15	20% minder dan origineel	18 minuten	Gemiddeld 5 minuten wachten
4	18	€ 15	Hetzelfde als origineel	18 minuten	Gemiddeld 5 minuten wachten
4	18	€ 25	20% meer dan origineel	12 minuten	Gemiddeld 15 minuten wachten
4	19	€ 15	Hetzelfde als origineel	6 minuten	Gemiddeld 15 minuten wachten
4	19	€ 25	20% minder dan origineel	12 minuten	Gemiddeld 5 minuten wachten
4	20	€ 15	Hetzelfde als origineel	12 minuten	Gemiddeld 10 minuten wachten
4	20	€ 25	20% minder dan origineel	6 minuten	Gemiddeld 5 minuten wachten
5	21	€ 35	20% meer dan origineel	6 minuten	Gemiddeld 5 minuten wachten
5	21	€ 25	Hetzelfde als origineel	18 minuten	Gemiddeld 15 minuten wachten
5	22	€ 15	20% meer dan origineel	6 minuten	Gemiddeld 5 minuten wachten
5	22	€ 35	20% minder dan origineel	18 minuten	Gemiddeld 10 minuten wachten
5	23	€ 25	20% meer dan origineel	6 minuten	Gemiddeld 10 minuten wachten
5	23	€ 35	Hetzelfde als origineel	12 minuten	Gemiddeld 5 minuten wachten
5	24	€ 25	Hetzelfde als origineel	12 minuten	Gemiddeld 5 minuten wachten
5	24	€ 35	20% meer dan origineel	6 minuten	Gemiddeld 10 minuten wachten
5	25	€ 25	Hetzelfde als origineel	12 minuten	Gemiddeld 5 minuten wachten
5	25	€ 15	20% minder dan origineel	18 minuten	Gemiddeld 15 minuten wachten

E. Descriptive tables of survey results

Survey results on socioeconomic characteristics

Occupation	Self-employed	Employed	Student	Incapacitated	Retired	Unemployed	Housewife /Husband	Unknown
Collected (%)	12,6	65,9	1,6	1,6	15,4	0,5	0,5	1,6
MPN (%)	3,6	47,2	10,9	5,5	20,5	3,0	7,3	1,9

Income	Minimum	Below average	Average	1-2x Average	2x Average	More than 2x average	Unknown
Collected (%)	1,3	8,2	18,4	29,1	11,4	20,9	10,8
MPN (%)	6,3	19,5	22,3	24,7	4,9	6,7	15,6

Age	18 - 29 years	30 - 39 years	40 - 49 years	50 - 59 years	60 years or older	Unknown
Collected (%)	12,6	19,8	12,1	18,1	20,9	16,5
MPN (%)	19,2	18,6	15,1	17,8	29,3	0,0

Household composition	Couple with children	Couple without children	Single	One-parent family
Collected (%)	24,7	38,0	35,4	1,9
MPN (%)	27,8	28,8	36,6	6,5

Household size	1 Person	2 Persons	3 Persons	4 Persons	5 Persons	More than 5 persons
Collected (%)	34,2	41,1	6,3	16,5	0,6	1,3
MPN (%)	36,2	32,6	11,4	14,1	4,3	1,4

Car ownership	No cars	1 car	2 cars	3 or more cars	Car driver's license	No car driver's license
Collected (%)	47,6	48,8	3,6	0,0	85,4	14,6
MPN (%)	19,7	54,6	18,8	6,9	87,2	12,8

Reason for car ownership	Least amount of effort to reach my destinations.	Sense of control or a sense of freedom.	Better mobility than all other transport modes.	Most amount of personal space when travelling.	Least monetary costs involved.	Other
Collected (N)	21	22	29	3	2	11

Survey results on transportation characteristics (all in %)

Current travel mode	Walking	(Electric) Bike	Train	Bus/Tram/ Metro	Car (as driver)	Car (as passenger)	Motor, Scooter, Moped	Other
Collecte	7,7	49,5	15,9	0,5	21,4	2,2	0,0	2,7
MPN	0,9	7,9	6,0	3,2	51,3	2,2	4,7	23,9
Preferred travel mode	Walking	(Electric) Bike	Train	Bus/Tram/ Metro	Car (as driver)	Car (as passenger)	Motor, Scooter, Moped	Other
Collected	6,7	64,2	12,3	2,2	12,3	0,6	0,6	1,1
MPN	3,4	34,8	3,2	2,2	52,4	0,0	3,2	0,7

Satisfaction travel mode	Very dissatisfied	Dissatisfied	Somewhat dissatisfied	Neutral	Somewhat satisfied	Satisfied	Very satisfied
Walking	0,0	0,0	0,0	0,0	0,0	14,3	85,7
(Electric) Bike	0,0	1,1	0,0	0,0	1,1	20,0	77,8
Train	0,0	3,4	6,9	3,4	10,3	44,8	31,0
Bus/Tram/Metro	0,0	0,0	0,0	0,0	100,0	0,0	0,0
Car (as driver)	0,0	5,1	5,1	2,6	10,3	59,0	17,9
Car (as passenger)	0,0	0,0	0,0	0,0	0,0	100,0	0,0

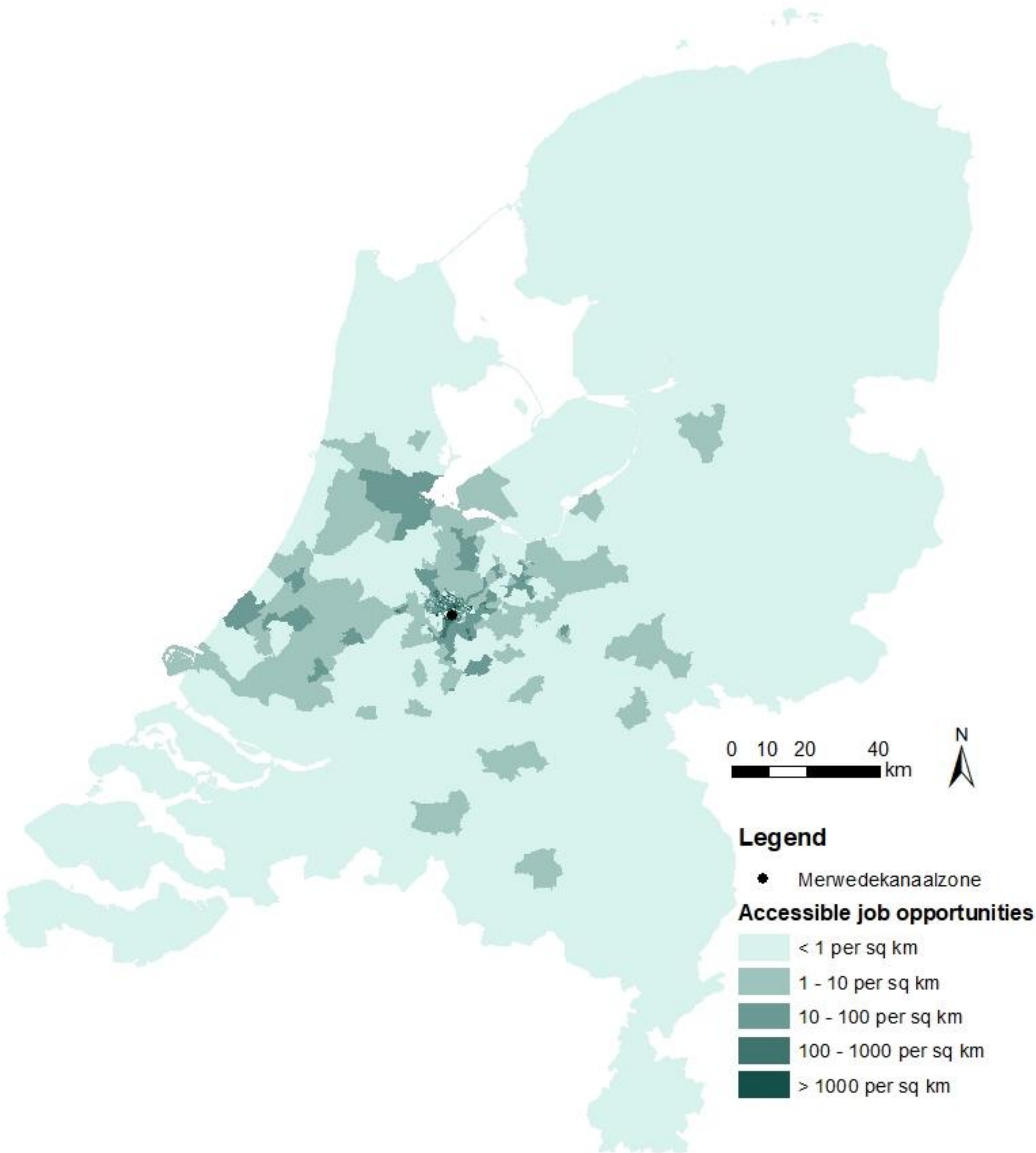
Satisfaction travel time	Very dissatisfied	Dissatisfied	Somewhat dissatisfied	Neutral	Somewhat satisfied	Satisfied	Very satisfied
Walking	0,0	0,0	0,0	0,0	0,0	14,3	85,7
(Electric) Bike	1,1	0,0	0,0	2,2	1,1	21,1	74,4
Train	0,0	10,3	27,6	3,4	10,3	34,5	13,8
Bus/Tram/Metro	0,0	0,0	0,0	0,0	0,0	100,0	0,0
Car (as driver)	0,0	2,6	2,6	10,3	15,4	59,0	10,3
Car (as passenger)	0,0	0,0	0,0	0,0	0,0	100,0	0,0

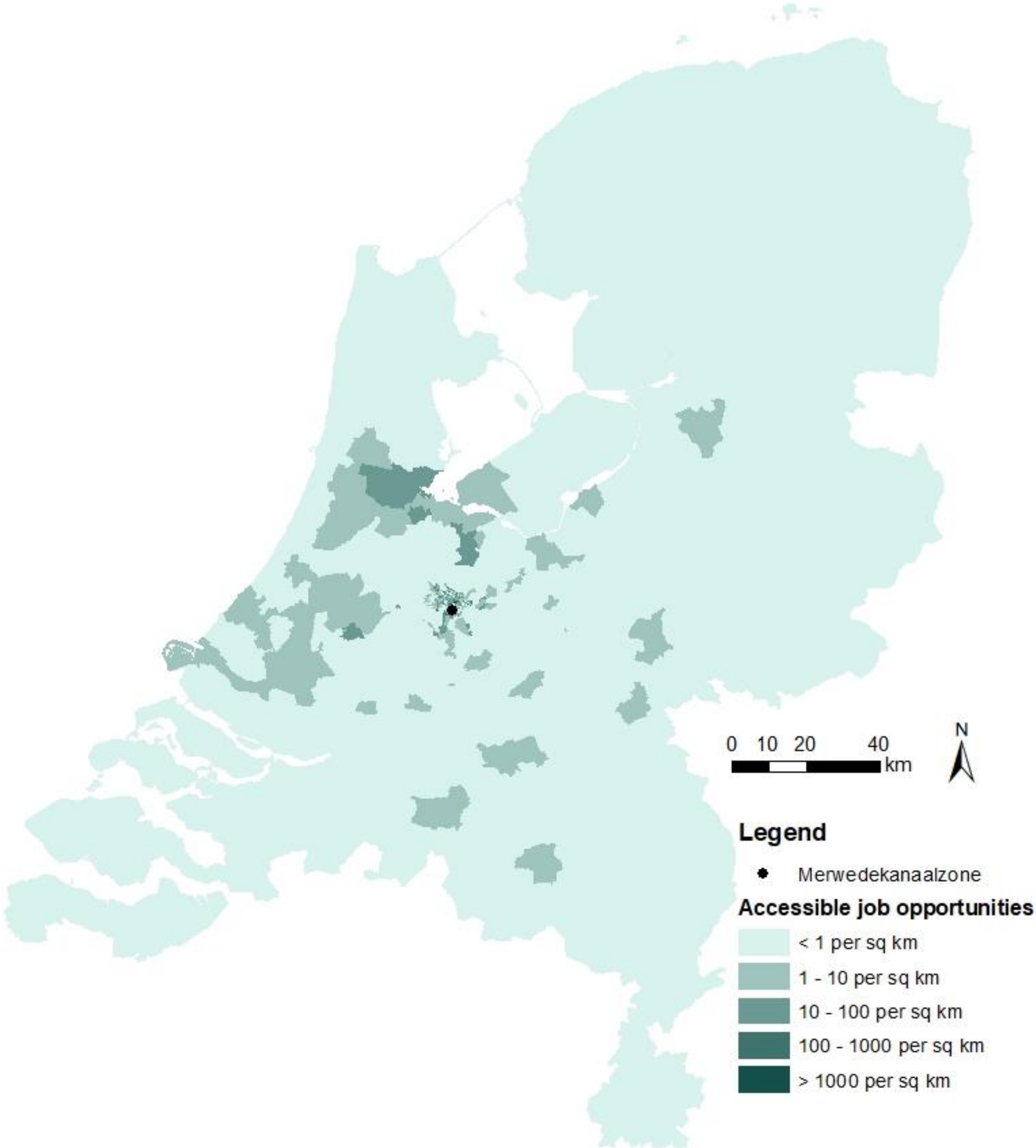
Transport usage	Private car	Shared car	Private bike	Shared bike	Private moped	Shared moped	Train	Bus/Tram/ Metro
Less than once per 3 months	64,6	110,8	14,6	110,8	131,5	129,2	41,5	43,1
1 to 2 days per 3 months	3,1	12,3	2,3	12,3	0,0	2,3	35,4	32,3
1 to 3 days per month	16,9	7,7	3,1	8,5	0,8	1,5	28,5	40,8
1 to 3 days per week	30,8	3,1	20,8	2,3	1,5	0,8	17,7	13,1
More than 3 days per week	18,5	0,0	93,1	0,0	0,0	0,0	10,8	4,6

Survey results on transportation characteristics (all in %)

Presence transport modes	Shared car	Shared bike	Shared moped	Train station	BTM station		
Yes	78,0	25,8	29,1	40,7	90,7		
Do not know	15,4	47,8	57,1	1,1	0,5		
No	1,1	20,9	8,2	52,7	3,3		
Attitude towards transport modes	Very negative	Negative	Somewhat negative	Neutral	Somewhat positive	Positive	Very positive
Private car	12,2	11,6	15,5	7,7	9,4	21,0	14,9
Shared car with acquaintance	3,9	6,6	10,5	19,9	10,5	26,0	14,9
Shared car with stranger	13,3	26,0	23,8	18,2	5,0	4,4	1,7
Train	0,6	1,1	3,3	8,3	11,6	31,5	35,9
Bus/Tram/Metro	0,6	2,8	6,6	16,0	21,0	27,1	18,2
Moped	29,8	26,5	9,4	21,0	0,0	4,4	1,1
Motor	26,5	22,7	8,8	27,6	0,6	3,9	2,2
Regular bike	0,0	1,1	0,6	2,8	3,9	12,2	71,8
E-bike	2,2	6,1	7,7	19,3	18,2	23,2	15,5

F. Class accessibility in the Netherlands

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