Transition towards 10-minute city Utrecht: Research on Overvecht and Kanaleneiland

BSc Civil Engineering

Proposal BSc Thesis

Luca Dommerholt - S2592967

Company: Goudappel

Supervisors: Richard ter Avest (Goudappel) &
Karst T. Geurs (University of Twente)

Period: 17-04 until 23-06

4th July 2023

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Preface

The reason of writing this report is my interest in projects on area development. The subject of the 10-minute accessibility gave me the opportunity to think about ways to improve accessibility by stimulating more usage of sustainable transport modes and by implementing more services in the areas itself. I would like to thank Goudappel, especially Richard ter Avest for giving the opportunity to do such a thesis at the office, and furthermore for providing me with an assignment and for his help during the time of the thesis. Furthermore, I would like to thank Karst T. Geurs for the help on my report, for providing me with theory and sources and for his help with the procedure of the calculations.

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Executive summary

The municipality of Utrecht has plans to make the transition towards a 10-minute city. The concept of a 10-minute city is that essential destinations (such as schools, jobs and parks) are accessible within 10 minutes. (MunicipalityUtrecht, 2021, p.27) Accessibility refers to the extent to which these destinations can be reached by several means of transport. Cycling and walking should be stimulated and instead, car usage needs to be reduced (MunicipalityUtrecht, 2021, p.16). For destinations further away, there should be the possibility to take public transport within 10 minutes (MunicipalityUtrecht, 2021, p.27).

However, Utrecht is not yet a 10-minute city for everyone since, in some parts of Utrecht, destinations are not accessible within 10 minutes. Two of these areas are Overvecht and Kanaleneiland, where the number of people with a low income and a non-western background is high. Therefore, this research aims to analyze the accessibility to destinations by driving, cycling, and walking within 10 minutes for these two areas for these two socio-economically weak groups.

The main research question is as follows: Which socioeconomic characteristics in the areas of Overvecht and Kanaleneiland have a low score on accessibility, for which parts of the areas is this the case, and what are the reasons behind these low scores of accessibility? The first subquestion is as follows: Which socioeconomic characteristics influence the degree to which residents have access to essential destinations within 10 minutes of travel time in Overvecht and Kanaleneiland, taking into account the availability and usability of several transport modes, and in which parts of these two areas is this influence the highest? The second subquestion is as follows: What is the impact of the distribution of services on the 10-minute accessibility in Overvecht and Kanaleneiland, and in which parts of these two areas does the distribution of services influence accessibility?

The research methods used are as follows. At first, ArcGIS is used to calculate for several locations in Utrecht the isochrones. These are polygons that show, from several locations, the areas accessible within 10 minutes. Then, the isochronic measure was used to measure accessibility by counting the number of destinations within each isochrone per destination type. This accessibility was calculated for several locations in Utrecht for driving, cycling, and walking. These transport modes have been weighed by modal availability and modal split. Modal availability refers to the percentage of vehicle ownership in households. Modal split refers to the percentage of transport mode usage of people. Based on these percentages, the accessibility measures of the three means of transport have been combined. These steps were carried out for all services separately. Therefore, the services had to be combined by normalizing the accessibility values of the services, multiplying them with the weights of the services, and summing all services. The weights are based on how often destination types are visited and are calculated in percentages. After that, the final accessibility values were compared to people with a low income and people with a non-western background. It has been analyzed what the impact of these socioeconomic characteristics is on the accessibility of destinations and where these relations are found in Overvecht and Kanaleneiland. Lastly, the impact of the distribution of services on the accessibility of destinations has been analyzed. It has been determined for the several socioeconomic characteristics in Overvecht and Kanaleneiland what percentage of people can reach the several destination types. For the destination types with low percentages, the locations in Overvecht and Kanaleneiland where accessibility values and the number of reachable destinations are low have been determined.

For people with a low income and non-western background, car and bike ownership in Overvecht and Kanaleneiland is low, and the number of households without any ownership of vehicles is high.

Furthermore, car usage is low for people with a low income; instead, more people are cycling or walking. Also, car usage among people with a non-western background is low. For both socioeconomic groups, this results in a low 10-minute accessibility in the northwest of Overvecht and a low 10-minute accessibility in the west of Kanaleneiland. On the other hand, car usage among people with a non-western background is high. This high car usage makes the 10-minute accessibility higher, especially in the northwest of Overvecht. However, since car usage does not fit in a 10-minute city, car usage should be reduced if the municipality of Utrecht wants to realize the 10-minute city. Looking at the distribution of destinations in Overvecht, bars/restaurants, commercial destinations, jobs, and sports facilities are not accessible within 10 minutes by driving, cycling, and walking. In Kanaleneiland, this is the case for commercial services, healthcare services, and jobs. Therefore, if the municipality of Utrecht wants to realize a 10-minute city, the 10-minute accessibility to these services should be improved.

In conclusion, in Overvecht and Kanaleneiland, people with low-income and non-western backgrounds can reach fewer services within 10 minutes. Therefore, the idea of a 10-minute city is not yet achieved. Firstly, this is because of the low availability of cars and bicycles for both socioeconomic groups. Secondly, this is because of low bike usage among non-western people. Thirdly, car usage, which does not fit in a 10-minute city, is relatively high for people with a non-western background. Lastly, the 10-minute city still needs to be achieved because some services cannot be reached within 10 minutes for people with low-income and non-western backgrounds.

1 Introduction

Goudappel, where the BSc thesis is carried out, is a consultancy firm where work is conducted on improving neighborhoods, data analysis, traffic flows, etcetera. One of the current projects at Goudappel is on the plans of the municipality of Utrecht to transition towards a 10-minute city. (MunicipalityUtrecht, 2021) This is the main subject of my BSc thesis project. The concept of a 10-minute city is that essential destinations (such as schools, jobs and parks) are accessible within 10 minutes. (MunicipalityUtrecht, 2021, p.27) Accessibility refers to the extent to which these destinations can be reached by several means of transport.

Utrecht is the fastest-growing city in The Netherlands. From 2020 to 2040, the number of inhabitants will increase from 350000 to 455000. It means the number of new homes needs to increase from 60000 to 70000 working places. Furthermore, additional greenery has to be implemented in the city. These developments require extensive investments in the mobility infrastructure to improve accessibility to these destinations. (MunicipalityUtrecht, 2021, p.16)

In order to improve accessibility for all the inhabitants to the several destinations, the municipality of Utrecht has plans to transition towards a 10-minute city. Essential destinations (such as schools, jobs, and parks) should be accessible to everyone living in Utrecht within 10 minutes. Within this 10-minute city, walking and cycling should be stimulated for close destinations. (MunicipalityUtrecht, 2021, p.16) For destinations further away, public transport should be stimulated. (MunicipalityUtrecht, 2021, p.27) On the contrary, car usage has to reduce. (MunicipalityUtrecht, 2021, p.16) The problems of accessibility within 10 minutes for the inhabitants is the core of this article.

Section 2 will explain the problem description and the research objective. In Section 3, the literature review for my research will be provided. Section 4 will explain the research questions. In Section 5, the study area and datasets will be provided. Then, in Section 6, the research methods and techniques will be explained. After that, the results will be shown in Section 7, providing answers to the subquestions. Next, in Section 8, a conclusion will be given to answer the main research question. Lastly, in Section 9, a discussion and recommendations for further research will be provided.

2 Research objective

2.1 Problem description

Several zones in the city of Utrecht differ based on socio-economical characteristics. Many of these socio-economical characteristics are weak in two zones of Utrecht: Overvecht and Kanaleneiland. For example, there are many low-income people in these two areas. In Utrecht, the percentage of households with a low income is the highest in Overvecht and Kanaleneiland: in Overvecht, this is 30,3%, and in Kanaleneiland, this is 18,5%. (MunicipalityUtrecht, 2023) Because of these high percentages of low incomes, many people in Overvecht and Kanaleneiland cannot afford means of transport. Therefore, it is relevant to know what is the score of accessibility to essential destinations in these two areas (such as schools, jobs and parks) and on which socioeconomic groups this has an impact.

2.2 Research objective

This thesis aims to determine which socioeconomic characteristics in Overvecht and Kanaleneiland in the areas of Overvecht and Kanaleneiland do not have a 10-minute neighborhood lifestyle and why this is not yet the case. Firstly, there will be research on what the score of accessibility is in several parts of the areas of Overvecht and Kanaleneiland for several socioeconomic groups. Then the relationship between accessibility measures and socioeconomic characteristics will be discovered. Furthermore, the relationship between accessibility measures and the distribution of destinations will be discovered.

3 Literature review

Before starting this research, a literature review has been made to set up research methods. Section 3.1 mentions some of the X-minute cities used in other studies. Section 3.2 mentions some accessibility measures and their relation to some X-minute cities. Section 3.3 shows some services used in research on a 10-minute city. After that, Section 3.4 mentions a comparison of accessibility and sociodemographic variables in research on a 10-minute city. Lastly, Section 3.5 provides the conclusion of this theoretical framework with a link to the research questions.

3.1 X-minute city in other studies

The concept of an X-minute city has been used in many different studies, and they all had different points of view. One of the many studies is a study of Kesarovski & Hernandez-Palacio (2022), which focuses on the accessibility to groceries within 10 minutes in the Stavanger metropolitan area in Norway, based on a GIS analysis. Furthermore, a study by Staricco (2022) focused on comparing 5-minute, 10-minute, and 15-minute accessibility to several services in the city of Turin in Italy. Another study comes from di Marino et al. (2022), which focused on the accessibility to new working spaces (NWS) by comparing accessibility within 10 minutes and accessibility within 15 minutes. The last study discussed here comes from Knap (2022), which focused on investigating the role of accessibility on spatial and socioeconomic inequalities in Utrecht and other surrounding places. Her study only took into account bicycles, so other means of transport were not considered.

As shown in all these kinds of studies, the focus of studies on X-minute cities is extensive. They can determine the accessibility to particular services. Alternatively, they can determine accessibility based on particular transport modes. Furthermore, they can distinguish between several X-minute cities and the accessibility to services. Furthermore, they can also determine the correlation between the accessibility in X minutes and some other feature (such as the correlation between the accessibility within X minutes and spatial and socioeconomic factors).

3.2 Accessibility measures and relation to the X-minute city

3.2.1 Finding the right accessibility measure for each service

Accessibility measures have been explained in several studies and theory books. Geurs & van Eck (2001) and Knap (2022) mentioned some of the accessibility measures: distance-based measures and gravity-based measures. Furthermore, Geurs & van Eck (2001) and Kesarovski & Hernandez-Palacio (2022) both mentioned the isochronic measure. Lastly, Knap (2022) used the 2-step floating catchment area. Distance-based measures determine the distance between an origin and a distance. Distance-based measures are easy to conduct; however, the measure is only possible between two points. Isochronic measures determine the number of services reached within X minutes of traveling. In the study of Kesarovski & Hernandez-Palacio (2022), the isochronic measure calculates the number of points of interest within each polygon. This measure is easy to explain; however, one disadvantage is that it does not consider the weights of travel times and travel distances. The gravity-based measure takes into account the disadvantage of the contour measures. It counts the number of services, but it considers a weight, based on the travel time or distance, to determine how likely it is that the travel to a particular destination will be made (by using an impedance function). The 2-step floating catchment area can be used in case there is supply and demand between the origin and destination.

3.2.2 Combining transport modes

The report of Levinson & Wu (2020) mentions a possible way to combine the accessibility of several transport modes, which is by modal availability. It is based on the idea that people owning certain means of transport have more possibilities to access specific locations (opportunities). Equation 1 shows how to calculate modal availability.

$$A^{**}_{i,h,z,.,e,t,p} = \sum_{m=1}^{M} \sum_{j=1}^{J} V_{i,m} O_{j,h,z} f(C_{ij,m,e}) \tag{1}$$

$A^{**}_{i,h,z,.,e,t,p}$ measures the accessibility of all considered means of transport integrated. m going from 1 to M corresponds to the types of vehicle ownership, and j from 1 to J is used for several destinations. $V_{i,m}$ shows the percentage of the type of vehicle ownership and is shown in Equation 2.

$$V_{i,m} \in (0,1), \sum_{m=1}^{M} V_{i,m} = 1 \tag{2}$$

As shown, $V_{i,m}$ has to be a value between 0 and 1. Furthermore, the sum of all types of vehicle ownership should be equal to 1. For example, in the case of car availability, V_{car} is the share of people who own a car, and $V_{\overline{car}}$ is the share of people who do not own a car (which is 1 - V_{car}). Furthermore, $O_{j,h,z}$ refers to several opportunities (the number of destinations accessible per destination type), and $f(C_{ij,m,e})$ is the impedance function.

3.3 Services and normalized scores in accessibility measures

In order to measure the accessibility, it is essential to know the most important destinations in Overvecht and Kanaleneiland. Therefore, it has been determined which destinations have been used in other studies to measure accessibility. The study of Knap (2022) has analyzed the essential destinations, whose analysis was also on the region of Utrecht. Her study focused on ten different destinations, 1) commercial, 2) food, 3) entertainment, 4) education, 5) bars and restaurants, 6) healthcare, 7) sports, 8) parks, 9) recreation, and 10) jobs. The data of all these services have been received from the OSM data with points of interest and parks and recreation areas. Only general practitioners have been considered in healthcare since this is the only type of healthcare contributing to the daily services in the area. Parks are green spaces, and they are received from polygons with points on the edges as entrances connecting to the road network in case of areas bigger than 0.2 km^2. Next, data about jobs has been gotten in a data source of BAG and provides information about the number of jobs per building. Data about jobs, commercials, and bars and restaurants have been aggregated, meaning the number of services is provided in cells.

These services were used for the accessibility calculations using the contour measures and the 2-step floating catchment area approach. Accordingly, all accessibility measures have been normalized using the min-max normalization and combined by calculating the final metric CS (city score): an accessibility measure, including all services. For this part, the weights of the services were received from the Dat.mobility dataset with the recorded trips.

3.4 Comparison of accessibility with socio-demographic variables

A comparison of accessibilities with socio-demographic variables has been done in the study of Knap (2022) in which the Bivariate Local Moran's I has been used to compare CS-values, mentioned in Section 3.3, and the socio-demographic variable. For example, a comparison has been made between the CS and the percentage of immigrants. A distinction is made between a high-high cluster, a low-high cluster, a high-low cluster, and a low-low cluster. A high-high cluster means a high CS value and a high percentage of immigrants. A low-low cluster means both a low CS value and a low percentage of immigrants. A low-high cluster means a low CS value and a high percentage of immigrants. And a high-low cluster means a high CS value and a low percentage of immigrants. In the measure of Bivariate Local Moran's I, the prediction of a location is influenced by the dependent variables of its neighbors. These neighbors can be "Queen" and "Rook" spatial weights. The "Queen" spatial weights consider all edges and vertexes of the cell. The "Rook" spatial weights consider only the edges of the cell.

3.5 Conclusion of the literature review

From the literature review, much information is already known. From the studies of Kesarovski & Hernandez-Palacio (2022), Geurs & van Eck (2001), and Levinson & Wu (2020), information is provided on different ways to measure accessibility. Furthermore, information is provided by Kesarovski & Hernandez-Palacio (2022), Staricco (2022), and di Marino et al. (2022) on research into other cities making the transition towards an X-minute city. Lastly, research on the role of accessibility on spatial and socioeconomic inequalities in Utrecht and other surrounding places has also been provided by the study of Knap (2022), including destination types considered. What has not yet been considered, in comparison to the study of Knap (2022), is how accessibility influences socioeconomic characteristics and spatial distributions considering driving, cycling, and walking. The study of Knap (2022) was only based on cycling. Furthermore, Knap (2022) focused on the whole of Utrecht and other surrounding cities, and therefore no detailed results are provided for the areas of Overvecht and Kanaleneiland. So it will be researched which socioeconomic characteristics and destination types influence the accessibility in Overvecht and Kanaleneiland to contribute to the 10-minute city, considering driving, cycling, and walking, which will be explained in Section 4.

4 Research questions

The research questions exist of one main research question and two subquestions.

The main research question is: Which socioeconomic characteristics in the areas of Overvecht and Kanaleneiland have a low score on accessibility, for which parts of the areas is this the case, and what are the reasons behind these low scores of accessibility?

The subquestions are as follows:

1. Which socioeconomic characteristics influence the degree to which residents have access to essential destinations within 10 minutes of travel time in Overvecht and Kanaleneiland, taking into account the ownership and usability of several means of transport, and in which parts of these two areas is this influence the highest?
2. What is the impact of the distribution of services on the 10-minute accessibility in Overvecht and Kanaleneiland, and in which parts of these two areas does the distribution of services influence accessibility?

5 Study area and data sets

5.1 Study area

The study area of the research will consider all neighborhoods within the municipality of Utrecht. The focus lies on Overvecht and Kanaleneiland; however, the differences in accessibility, on the one hand, and socio-economic characteristics and spatial characteristics, on the other hand, throughout Utrecht should become visible. In this way, it can be determined if accessibility and spatial distribution of destinations in Overvecht and Kanaleneiland are low compared to other areas. Therefore, all neighborhoods in Utrecht will be considered. The study area is shown in Figure 3.

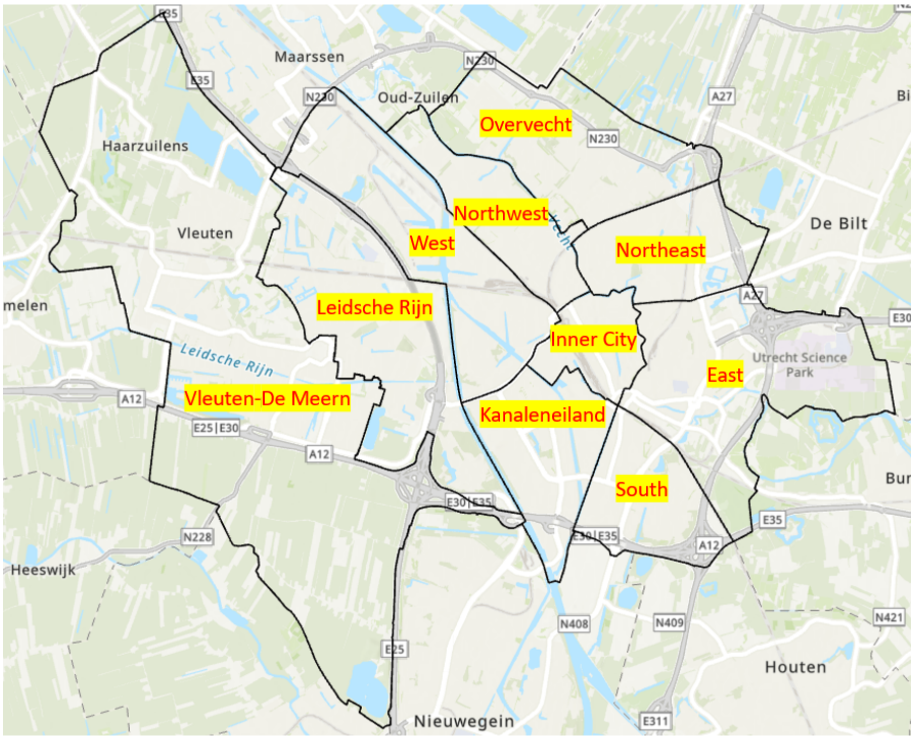


Figure 3: Study area

Figure 3 shows ten neighborhoods within Utrecht: West, Northwest, Overvecht, Northeast, East, Inner City, South, Southwest, Leidsche Rijn, and Vleuten-De Meern. The analysis will be done for the entire area, and finally, the results will be based on the areas of Overvecht and Kanaleneiland.

5.2 Data sets

Several data sets will be used for this research, shown in Table 1.

Table 1: Data sets

Data	Desciption	Source	Period
Car network	Network with car roads in the provinces Flevoland, Gelderland, Noord-Brabant, Noord-Holland, Zuid-Holland and Utrecht	OSM	2023
Bicycle network	Network with bicycle roads for the whole of The Netherlands	Fietsersbond	2021
Pedestrian network	Network with pedestrian roads for the whole of The Netherlands	Fietsersbond	2021
500-by-500 metre grid	Layer of the whole of the Netherlands represented by 500-by-500 metre pixel with information on sociodemographical aspects	CBS	2018
Points of interest	Two layers with points of interests, one with points and one with polygons	OSM	2023
Public transport stops	GTFS layer with Transit Network including public transport stops	OVapi	5th of April 2023
Number of working places	Layer with number of working places per building	BAG, Dat.Mobility	2023
Modal availability	Data with modal availability per income class	OVIN	2010-2017
NVP data	Data from NVP on the weight of destination types based on recorded trips	Dat.mobility	2023

As can be seen in the Table, three road networks will be used. The car network is received from OSM data (Geofabrik, 2023), and the bicycle and pedestrian network are received from "Fietsersbond." Next, a 500-by-500 meter grid from CBS is used, which provides information on some of the socio-demographic aspects of The Netherlands per 500-by-500 meter pixel. (CBS, 2018) Furthermore, points of interest from OSM, a GTFS layer from OVapi (OpenMobilityData, 2023), and a layer with the number of working places from BAG are used for the destination types. Next, data from OVIN will be used to determine vehicle ownership, and data from ODIN will be used to determine usage of means of transport. Lastly, NVP data is used to determine the weight of each destination type.

6 Research methods and techniques

6.1 Setting up polygons with 10-minute accesibilities

6.1.1 GIS-analysis on 10-minute accessibilities

In order to determine the accessibility within 10 minutes to destinations, quantitative research will be carried out. The software that will mainly be used for this is ArcGIS. As explained in Section 3.1, the study of Kesarovski & Hernandez-Palacio (2022) focused on a GIS analysis. In this GIS analysis, he derived polygons from 275 locations in the Stavanger metropolitan area based on the areas that can be accessed within 10 minutes. The polygons have been derived using the Network Analyst: a tool in GIS software used, among other things, to determine locations accessible within 10 minutes. The derivation of polygons will also be the procedure for my GIS analysis. The methodology in the study of Kesarovski & Hernandez-Palacio (2022) describes three operations that must be taken. Those are data preparation, executing GIS analysis, and processing linear regression. Processing linear regression will not be essential for my research.

Data preparation is focused on finding data that can be implemented into GIS software. For my study, for the cars, this will be the OSM dataset with roads as shown in Table 1 in Section 5.2. It is an osm.pbf file that must be converted into a shapefile using osm2po and PostGIS. For cyclists and pedestrians, another data source will be used, which is called "Fietsersbond." The roads of all these datasets will be used to create road networks in ArcGIS. These road networks can accordingly be used to execute the GIS analysis by the Network Analyst. (ArcGISPro3.1, 2023). The points of interest for the execution of the GIS analysis will be the midpoints of the grid cells coming from the 500-by-500-meter grid of CBS, whose data set has also been mentioned in Table 1 in Section 5.2.

After the execution of the GIS analysis, from all the midpoints, isochrones will be provided. These are polygons based on areas reachable within 10 minutes. In my research, the isochrones are considered for driving, cycling, and walking. Different velocities must be considered for each transport mode, and some restrictions exist. Furthermore, the isochrones from the Network Analysts will be verified by a tool named "MapItOut." (MapItOut, 2023) With this tool, it is possible to enter an address and to determine the reachable area within a particular amount of minutes (15, 30, 45, or 60 minutes) for a particular transport mode (car, bike and foot). It is assumed that the isochrones provided by "MapItOut" are reliable and that the isochrones of ArcGIS should be approximately the same. The verification procedure is shown in Appendix A.

For the car, the road types on which the cars are allowed to drive, and thus will be taken into account for the GIS analysis of cars, are living streets, motorways, motorway links, primary roads, primary road links, residential roads, secondary roads, secondary road links, tertiary roads, tertiary road links, trunk roads, trunk road links, and unclassified roads. The velocities that will be considered are the maximum velocities provided by the OSM data with roads. It is assumed that this is the speed driven by the cars. The travel time of each road has been calculated by dividing the length of each road by the maximum speed that can be driven on each road segment. What is furthermore essential is that cars are not allowed to drive against the direction of travel in case of one-way roads. One-way roads are recognized by information on the costs of each road for both directions. If the cost in the reverse direction has been set at 100000, it means that a particular road is one-way. For these roads, the travel time of the first direction and the travel time of the second direction will be calculated separately. The travel time of the first direction is again the length of each road segment divided by the maximum speed on each road segment. The travel time in the second direction will be 100000, coming from the costs. In this way, the Network Analyst will not choose this second direction of travel since the Analyst recognizes this as a direction that takes much time.

For the GIS analysis of bicycles, the speed limits that will be considered are the speed limits given by the data of "Fietsersbond." Also, for the analysis of bicycles, a restriction needs to be made that cyclists are not allowed to drive against the direction of travel. Also, information on each road segment's costs will be used here. In the case of one-way roads, the reverse direction has been set at 1000000. Just as done for the car analysis, also for the bicycle analysis, the travel times will be calculated by dividing the length of the road segments by the speed of the road segments, except for one-way roads where the reverse direction will be set on 1000000 based on the costs of the reverse direction in order to restrict people from traveling against the direction of travel on oneway roads. In the case of the bicycle network, a restriction on road types is not required since "Fietsersbond" provides all roads on which cycling is allowed.

For the GIS analysis of pedestrians, no information is provided in the data source of "Fietsersbond" regarding the speed of pedestrians. However, a field study of pedestrians walking speed and start-up time provided information about the speed of pedestrians for a younger age group between 14 and 64 and an older age group of 65 and older. (Knoblauch et al., 1996) According to the study, the average speed of the younger age group is 1.25 m/s (4.5 km/h), and for the older age group, this is 0.97 m/s (3.49 km/h). The speed that will be considered is the speed of the younger age group, which is 4.5 km/h. The travel time will be calculated by dividing the lengths of the road segments received from the dataset of "Fietsersbond" by the velocity of 4.5 km/h. For pedestrians, it is assumed that no one-way roads exist, so this restriction will not be made here. Also, in the pedestrian network, only roads on which people are allowed to walk are provided; therefore, a road-type restriction is not required.

6.2 Services for the accessibility measure

To measure accessibility within 10 minutes in Overvecht and Kanaleneiland, the essential destination types must be considered. Section 3.3 explained the used destination types by the study of Knap (2022). Since this study was also about the region of Utrecht, these destination types will also be used for my research. There will, however, be some changes in these destination types. Firstly, education will be separated into two destination types, one for elementary and secondary schools and one for colleges and universities, because the group of people going to elementary or secondary schools differs from those going to college or university. Secondly, an additional destination type will be considered, which is public transport stops, to determine the accessibility to public transport. The destination types with fitting destinations used for my study are shown in Table 2.

Table 2: Services to each destination type

Destination types	Destinations
Bars and restaurants	Bars, cafés, fast-food and restaurants
Commercial	Beauty shops, bicycle shops, bookshops, clothes, computer shops, furniture shops, gift shops, jeweller, kiosks, market places, mobile phone shops, outdoor shops, shoe shops, sports shops, toy shops and video shopss
Colleges and universities	Colleges and universities
Elementary and secondary schools	Schools
Entertainment	Cinemas, community centres, libraries, museums, nightclubs and theatres
Food	Bakeries, butchers and supermarkets
Jobs	Number of working places per building
Healthcare	Doctors
Parks	Parks
Public transport	All tram, bus and train stops
Recreation	Attractions, picnic sites and playgrounds
Sports	Sports centres and swimming pools

The OSM data sets with points of interest, one with points and one with polygons, will be used for commercial, bars/restaurants, elementary/secondary schools, colleges/universities, entertainment, food, healthcare, parks, recreation, and sports. (Geofabrik, 2023) These two data sets (points and polygons) will be summed; however, the polygons will not be considered at places where polygons and points overlap. Furthermore, the data set from BAG with the number of workplaces per building will be used for jobs. These number of working places have been calculated before by BAG itself by 1) considering all different types of working places, 2) determining a parameter of the average number of working places per squared meter for each type of working place, and 3) by multiplying for each working place this number (based on the type of working place) with the surface area of the working place. Another data set that will be used for my study is a data set on public transport stops taken from the Transit Network Template from OVApi (2023). The version downloaded will be the one from the 5th of April, 2023. All these data sets have been shown in Table 1 in Section 5.2.

In Section 6.3.1, it will be explained how, for each destination type, the accessibility will be measured using ArcGIS. After that, the accessibility measures with all destination types integrated for several parts of Utrecht will be calculated, which will be explained in Section 6.4.

6.3 Accessibility measures

This Section will mention all the accessibility measures used. Firstly, Section 6.3.1 will mention how the accessibility to destination types will be calculated for the means of transport car, bike, and foot. After that, in Section 6.3.2 and Section 6.3.3, two measurements to combine the means of transport will be explained. The first measurement used will be modal availability, explained in

Section 6.3.2, and the second measurement used will be modal split, explained in Section 6.3.3.

6.3.1 Isochronic measures

In order to make it possible to determine accessibility to services, the best accessibility measure needs to be chosen. For my research, a decision had to be made between two accessibility measures: the isochronic measure of Kesarovski & Hernandez-Palacio (2022) and the gravity-based measure of Vale & Pereira (2016). The decision can be declared based on the gravity-based equation explained in Equation 3.

$$A_i = \sum_j D_j F(c_{ij}) \tag{3}$$

In Equation 3, A_i is the accessibility measure, D_j shows the several destinations, and $F(c_{ij})$ is the impedance function which is a calculation of the friction of the distance. The impedance function shows how likely people are to travel that particular distance. The lower the impedance, the less probable it is that people undertake this journey. Therefore, the isochronic measure is used instead of the gravity-based equation: the impedance function is relevant for long distances, but since the accessibility measure is only 10 minutes, the friction of distance will be ignored, and the impedance function will not be used. So the accessibility measure will just be based on the count of services which is the goal of the isochronic measure. The isochronic measure will calculate the accessibility to the destination types mentioned in Table 2. For all destination types, the measure will be based on the number of services accessible within 10 minutes. There is an exception for jobs, where the measure is based on the number of working places accessible within 10 minutes. The isochronic measure will be used for accessibility by car, bike, and foot.

6.3.2 Modal availability

All means of transport considered in the isochronic measures must be combined into one accessibility measure. One of the measures that will be used is modal availability coming from the report of Levinson & Wu (2020), explained in Section 3.2.2. Modal availability refers to the types of vehicle ownership of households. Since fewer variables are needed than in Equation 1, a simplification has been made in Equation 4.

$$A_i = \sum_{m=1}^{M} V_{i,m} O_{i,m} \tag{4}$$

In this Equation, A_i is the accessibility measure after weighing by modal availability. Next to this, m stands for each type of vehicle ownership, and i refers to each 500-by-500-meter area somewhere in Utrecht. Furthermore, $V_{i,m}$ corresponds to the percentage of each type of vehicle ownership, and $O_{i,m}$ corresponds to the maximum accessibility of all transport modes.

One of the variables not considered in Equation 4 compared to Equation 1 is the impedance function because of the short maximum travel time of 10 minutes. Furthermore, j from 1 to J used for several destination types is also not considered since this is already used in the calculations explained in Section 6.3.1.

In my study, four types of vehicle ownership will be used, summing up to $V_{i,m} = 1$. The first is the share of people owning one or more cars but no bicycles. $O_{i,m}$ is assumed to be the maximum accessibility considering driving and walking. The second one is the share of people owning one or more bicycles but no cars. $O_{i,m}$ is assumed to be the maximum accessibility considering cycling and walking. The third is the share of people owning one or more cars and bicycles. $O_{i,m}$ is assumed to be the maximum accessibility considering driving, cycling, and walking. The last one is the share of people not owning any vehicle. $O_{i,m}$ is assumed to be the accessibility by foot.

The percentages of the types of vehicle ownership will be determined based on differences in socioeconomic characteristics within the areas of Utrecht. The data to calculate the percentages per type of vehicle ownership is received from OVIN datasets from 2010 to 2017. These are datasets where people are asked about aspects such as age, income, and number of transport modes owned. The socioeconomic characteristics considered are:

1. Income
2. Percentage of people with a non-western background
3. Percentage of people with benefits below pension state age
4. Percentage of one-parent families

Some restrictions will be set on this database: It can be the case that one person is interviewed more than one time, so it has been made sure that each interviewed person is considered only one time. The data set has been limited to only the places with a high degree of urbanization, meaning the places with 2500 or more addresses per km^2, since Utrecht belongs to one of the biggest cities in The Netherlands. It has been chosen to use more cities than only Utrecht since it provides more data which makes the calculations of the modal availability percentages more reliable. The unknown socio-economic characteristics will be deleted from the dataset.

An assumption will be made to determine whether car- or bicycle availability exists in a household. For bicycle availability, it is assumed that the number of bicycles in a household should be at least 0.5 of the number of households six years and older. For car availability, this should be at least 0.5 of the number of households aged 18 years and older. This assumption has been made since it can be the case that a household owns one or more cars or bicycles, but more is needed for the household size.

6.3.3 Modal split

The other measure used to combine the means of transport is modal split. This measure calculates the accessibility to services based on the usage of transport modes. Modal split is used to determine if the accessibility differs when considering the usage of transport modes instead of vehicle ownership. The Equation of the modal split is a derivation of Equation 4 of modal availability and is shown in Equation 5.

$$A_j = \sum_{n=1}^{n} V_{j,n} O_{j,n} \tag{5}$$

In this Equation, A_j is the accessibility measure after weighing by the modal split. Next, j from 1 to J corresponds to the three transport modes. The transport modes considered will be car, bike, and foot. Furthermore, $V_{j,n}$ corresponds to each transport mode's usage percentage. These are percentages of residents traveling by car, bike, and foot. Lastly, $O_{j,n}$ corresponds to the number of services accessible for each destination type per transport mode.

Also, in this measure, the calculation will be based on income, non-western background, benefits below state pension age, and one-parent households, as explained in Section 6.3.2. The percentage of transport mode usage of one-parent- and non-western households will be derived from ODIN data between 2018 and 2021 with information on driving, cycling, and walking frequencies. The restrictions of the ODIN data are the same as the restrictions of the OVIN data in Section 6.3.2 . Furthermore, the percentage of transport mode usage of low-income- and benefits households will be derived from the recorded trips, including the type of transport mode per trip, coming from Dat.mobility.

6.4 Accessibility including all destination types

After the calculations of the accessibility, the accessibility measures of all destination types have to be combined to get one overall accessibility calculation per 500 by 500-meter area. As explained in Section 3.3, in the study of Knap (2022), the normalized accessibility formula and the final metric formula have been used to integrate all services. Normalized accessibility is required because the range of accessibility for each destination type is different. Therefore, without the normalized accessibility measure, the accessibility of several destinations is not comparable. Two equations will be used. The first is the normalization accessibility and is shown in Equation 6.

$$X_{i,p} = \frac{A_{i,p} - min(A_{i,p})}{max(A_p) - min(A_p)} \tag{6}$$

In this Equation, $A_{i,p}$ shows the accessibility of origin i to destination p, and $X_{i,p}$ shows the normalized accessibility of origin i to destination p. Origin i refers to the midpoints of the cells of the 500-by-500 meter grid and destination p refers to the services. The quantities max(A_p) and min(A_p) show the maximum and minimum accessibility value of all origins. Accordingly, the normalized accessibility measures can be summed together based on the final metric formula shown in Equation 7.

$$CS_{x,i} = \sum_{p=1}^{P} w_p * X_{i,p} \tag{7}$$

In this Equation, $CS_{x,i}$ is the city score based on x-minute accessibility at origin i. In my research, the city score is based on 10-minute accessibility. Furthermore, w_p shows the weight of each destination type which will be calculated based on the NVP data of Dat.mobility for each socio-economic group. These weights will be determined by selecting and grouping all relevant destinations into the destination types according to Table 2 in Section 6.2. The weights of the destination types are shown in Appendix B. Table 6 in Appendix B.1 shows these weights per income group. In Table 7 in Appendix B.2, these weights are shown for residents with a non-western background and residents from one-parent households. Unfortunately, no information has been found for these groups in the NVP data. Therefore, it is assumed that the weights are the same in each area of Utrecht. Lastly, Table 8 in Appendix B.3 shows the weights based on people with benefits below the state pension age. Lastly, $X_{i,p}$ shows the normalized accessibility measures from Equation 6, of origin i to destination p. Origin i refers to the midpoints of the cells of the 500-by-500 meter grid and destination p refers to the destination types.

In my research, these Equations will be used to combine the accessibilities of all services determined by modal availability and modal split as explained in Section 6.3.2 and Section 6.3.3, and the outcomes will be used for comparison with the socio-economic groups and the distribution of services, as will be explained in Section 6.5 and Section 6.6.

6.5 Comparison between accessibility and socio-economic groups

After calculating the accessibility values, the comparison can be made with some socioeconomic groups in Overvecht and Kanaleneiland. The first part is that box plots will be made to show the relationship between socioeconomic characteristics and CS values. The socioeconomic characteristics on which the focus will be put will be income and non-western background. However, also, there will be a minor focus on people with benefits below the state pension age and people from one-parent households. After that, a comparison will be made between vehicle ownership and transport mode usage of each socioeconomic characteristic on the one hand and those of all people on the other hand. Then, firstly, box plots will be made to show a relation between vehicle ownership and CS values, and secondly, box plots will also be made to show a relation between transport modes usage and CS values. These box plots are only based on areas between 1.5 and 5 kilometers from the Central Station of Utrecht, approximately the minimum and maximum distance to Overvecht and Kanaleneiland, to prevent the influence of distance on the CS values. They will be made as verification to see if particular percentages of vehicle ownership or transport mode usage logically lead to low or high CS values. Also, grids will be provided for each socioeconomic group to see if outcomes of vehicle ownership and transport modes usage for each socioeconomic groups are visible in each 500-by-500 meter area in Overvecht and Kanaleneiland.

In Section 3.4, an explanation has been given, based on the study of Knap (2022), on the comparison between accessibility and socio-demographic aspects by using the tool Bivariate Local Moran's I. This tool will also be used in my study to determine the clusters between CS values and socioeconomic characteristics in several locations in Overvecht and Kanaleneiland. The software used to determine these clusters is GeoDa. In this way, it can be seen where in Overvecht and Kanaleneiland, socioeconomic characteristics affect 10-minute accessibility. The relevant clusters for low-income people are low-low (low CS value and low income), and the relevant clusters for non-western people are low-high (low CS values and high percentage of non-western households). The neighborhood relations will be based on the "Queen" spatial weights since the relations with edges and vertexes are relevant. These clusters will be made both for the accessibility values measured by modal availability and by the modal split. For all the clusters, the p-value will be set to 0.4. It is a high p-value; however, this value is decided because the socio-demographic variables and the CS-values that are less extreme are also interesting for research.

6.6 Comparison between accessibility and distribution of services

In Section 6.5, the procedure to compare the accessibility and socio-economic groups have been given. However, it can also be the case that there is low accessibility because of a low distribution of services. In order to determine this, from all midpoints of the 500-by-500-meter grid dataset, the number of services will be determined that are within a boundary of 1 kilometer for all destination types separately to determine if there is a lack of destination types in the areas of Overvecht and Kanaleneiland. Instead of the procedure mentioned in Section 6.5, the Univariate Local Moran's I will be used, another tool in GeoDa, to determine the low clusters of the CS values. Again, the p-value will be set at 0.4 to get more clusters. These clusters will only be made for services where the percentage of people of a socio-economic group that can reach these services is lower than 80%. It is assumed that the accessibility below this percentage is low. Furthermore, colleges and universities will not be considered since, in general, there are specific locations for these kinds of buildings.

In order to determine locations with a lack of services, some threshold will be set on the minimum acceptable amount of services per destination type, shown in Table 3.

Table 3: Minimum acceptible amounts of services per destination type

Destination type	**Minimum acceptible amount of services**
Bars and restaurants	15
Elementary- and secondary schools	2
Commercial	20
Entertainment	5
Food	5
Jobs	2000 (jobs)
Healthcare	2
Parks	1
Public transport	5
Recreation	20
Sports	3

For almost all destination types, these values are assumed except for healthcare. This value is based on the maximum number of patients per general practitioner, which is 2095. (Chad, 2022) In Overvecht and Kanaleneiland, the number of inhabitants varies below and above this value, and therefore, to be on the safe side, it has been decided that the minimum number of services accessible per 500-by-500 meter area with destination type healthcare should be at least two.

6.7 Literature study on the mobility of migrants

In order to get to know the reason behind accessibility within 10 minutes for non-western people, a report of Durand et al. (2023) from KiM Netherlands Institute for Transport Policy Analysis with information on the mobility of migrants has been analyzed. It has to be mentioned that this is not based on Overvecht and Kanaleneiland.

It has been mentioned that some non-western people regularly stay at home because of health issues or a language barrier. So these people use few services. Also, it is mentioned that the distance to work for people with non-western backgrounds is higher than others. Also, people with a non-western background feel the lack of privacy in public transport. There is a low bicycle ownership and bicycle usage among non-western people because it is not part of the culture; because of the safety issues experienced; because of the lack of knowing the traffic rules; because of fear of theft, or because it is intense to cycle or other people in the area do not cycle either. Also, people with a non-western background walk more, drive more and use regular public transport. Still, car ownership under people with a non-western background is lower than others.

Some solutions to improve accessibility for non-western people are mentioned:

- Shared mobility because the problem of theft is solved for people renting them.

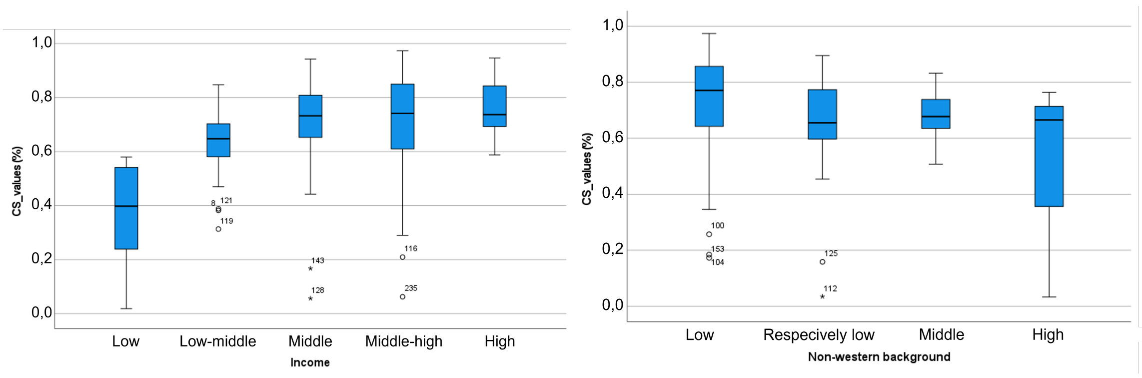
- E-bikes, especially for people with health issues, to reach services over a longer distance.
- A travel card on public transport with free trips or discounts.
- Children from parents with a non-western background should learn how to cycle.

7 Results

7.1 Relation between accessibility and socio-economic groups

7.1.1 Impact of socio-economic groups on the 10-minute accessibility in Overvecht and Kanaleneiland with modal availability as factor

In order to determine the influence of the socio-economic groups on the 10-minute accessibility, box plots have been made based on accessibility values weighed by modal availability, explained in Section 6.3.2. These box plots are shown in Figure 4.



(a) Income of people

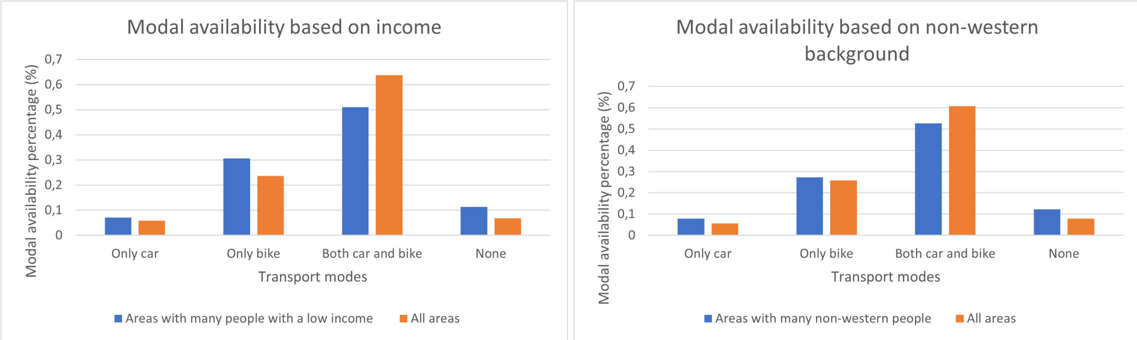
(b) People with non-western background

Figure 4: The relation between socioeconomic characteristics and accessibility considering vehicle ownership

In both Subfigures of Figure 4, the x-axis shows the socio-economic characteristic, in Figure 4a income and Figure 4b non-western background, and the y-axis shows CS values. In Figure 4a, a distinction is made between five classes based on the income level of people in an area. On the other hand, in Figure 4b, a distinction has been made between four classes based on the percentage of people with a non-western background living in an area. The box plots show the extent of the CS values based on the 95th percentile, which means that in 95% of the cases, the value falls within the box plot. The box plots vary from the minimum to the maximum, which means the lowest and highest number of the data set. The black line in the blue box shows the median of the data, which means the middle number. The blue boxes vary from the first to the third quartile of the data, which are the value halfway between the lowest and the middle number and the value halfway between the middle and the highest number. (Turney, 2022)

In the first subplot, Figure 4a, it can be seen that the CS values are relatively low in box plots with many low-income people. The minimum value, the value on the first quartile, the median value, the value on the third quartile, and the maximum value in the box plot of low-income people are lower than in the other box plots. The CS values are also low in box plots with a high percentage of non-western people, as shown in Figure 4b. The CS value in the first quartile in the box plot of many non-western people is lower than in other box plots. Furthermore, the minimum and maximum CS values are lower than in other box plots.

Figure 5 shows the vehicle ownership percentages for low-income and non-western people.



(a) Modal availability based on income (b) Modal availability based on non-western background

Figure 5: Comparison of vehicle ownership

As shown in Figure 5a, vehicle ownership in areas with households with a low income has been compared to vehicle ownership in all areas. Firstly, it is shown that in the areas with many households with a low income, households more often own only cars than on average in all areas. Also, in areas with many households with a low income, the percentage owning only bikes is higher than the average of all areas. The percentage of households with cars and bikes in areas with many households with a low income is lower than in all areas. The percentage of households with accessibility only by foot in areas with many households with a low income is higher compared to all areas.

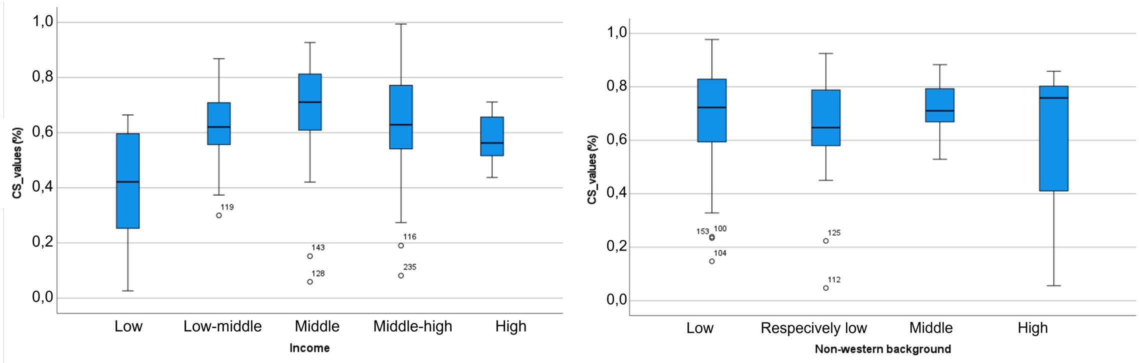
When looking at car availability in overall (households with only cars and households with cars and bikes), the percentage for low-income households is lower than the average percentage. For low-income households, this is 58,0%, while on average, this is 69,5%. Looking at bike availability (households with only bikes and households with cars and bikes), the percentage for low-income households is also lower than the average percentage. For low-income households, this is 81,7%, while on average, this is 87,2%. Lastly, the percentage of accessibility only by foot for low-income households is 11,3%, while on average, this is 6,8%.

In Figure 5b, it can be seen that vehicle ownership in areas with non-western households has been compared to vehicle ownership in all areas. Firstly, the percentage of households with only car availability in areas with many non-western households is higher than the percentage considering all areas. Also, the percentage of households with only bike availability in areas with many non-western households is higher than the percentage considering all areas. The percentage of households with car and bike availability in areas with many non-western households is lower than the percentage considering all areas. The percentage of households with accessibility only by foot in areas with many non-western households is higher compared to all areas.

When looking at car availability in overall (households with only cars and households with cars and bikes), the percentage for non-western households is lower than the average percentage. For non-western households, this is 60,4%, while on average, this is 66,3%. Looking at bike availability (households with only bikes and households with cars and bikes), the percentage for non-western households is lower than the average percentage. For non-western households, this is 79,9%, while on average, this is 86,5%. Lastly, the percentage of accessibility only by foot for non-western households is 12,3%, while on average, this is 7,9%.

7.1.2 Impact of socio-economic groups on the 10-minute accessibility in Overvecht and Kanaleneiland with modal split as factor

The influence of the socio-economic groups on the 10-minute accessibility has also been considered based on accessibility values weighed by the modal split, explained in Section 6.3.3. These correlations are shown in Figure 6.



(a) Income of people

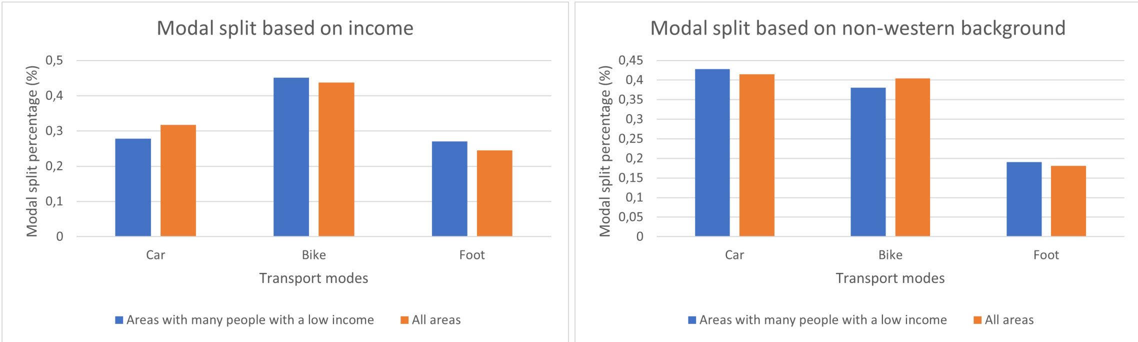
(b) People with non-western background

Figure 6: The relation between accessibility and socioeconomic characteristics considering the usage of transport modes

As shown in Figure 6a, the minimum, first quartile, median, third quartile, and maximum values in areas with many low-income people are lower than in other areas. These relations are the same as Figure 4a where modal availability has been used to weigh accessibility. So both using modal availability and modal split as weighing measures give the same relations.

In Figure 6b, in box plots with a high percentage of non-western people, the minimum value, the first quartile, and the maximum value are lower than in other box plots. Only the median and the third quartile are slightly higher. Therefore, the CS values are low in areas with many non-western people compared to other areas. However, in Figure 4b, the difference between the minimum, first quartile, third quartile, and maximum value in box plots with many non-western people, and those values in box plots with fewer non-western people is more extreme than in Figure 6b. Furthermore, in Figure 4b, the median and third quartile values in box plots with many non-western people are lower than in other areas. Therefore, the differences in CS values are less when considering modal split as weighing measure instead of modal availability.

Figure 7 shows the percentage of modal split based on income and the non-western background.



(a) Modal split based on income

(b) Modal split based on non-western background

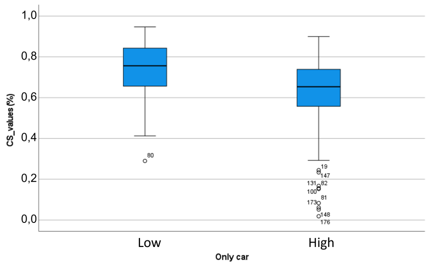
Figure 7: Comparison of transport mode usage

As shown in Figure 7a, the percentage of the transport mode usage in areas with households with a low income is compared to the percentage of the transport mode usage considering all areas. Firstly, the percentage of car usage in areas with many people with a low income is lower compared to the percentage considering all areas. In areas with many people with a low income, this is approximately 28%, while considering all areas, this is approximately 31%. The percentage of bike usage in areas with many people with a low income is higher than the percentage considering all areas. However, the difference is minor, in both cases approximately 45%. The percentage of walking in areas with many people with a low income is also higher compared to the percentage considering all areas. Also, in this case, the difference is negligible, approximately 25%.

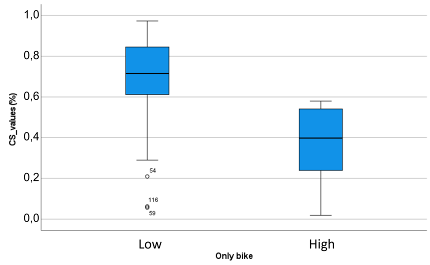
Figure 7b compares the percentage of the transport mode usage for non-western households to the percentage of the overall transport mode usage. The percentage of car usage in areas with many non-western people is higher than in all areas. The percentage is just above 40% in both cases. The percentage of bike usage in areas with many non-western people is lower than in all areas. In areas with many people with a low income, this is approximately 36%, while considering all areas, this is approximately 40%. The percentage of walking in areas with many non-western people is higher compared to considering all areas. The difference is also limited in this case: the percentage is just below 20% in both cases.

7.1.3 Impact of modal availability on the 10-minute accessibility

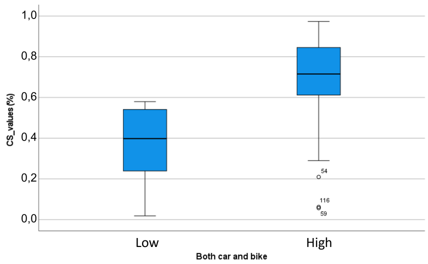
The impact of modal availability on the accessibility of 10 minutes in Overvecht and Kanaleneiland based on income has been plotted in Figure 8 into four graphs, one per modal availability type. The plots based on the non-western background are shown in Figure 35, and the plots based on the other socioeconomic aspects are shown in Figure 36, and Figure 37 (see Appendix D).



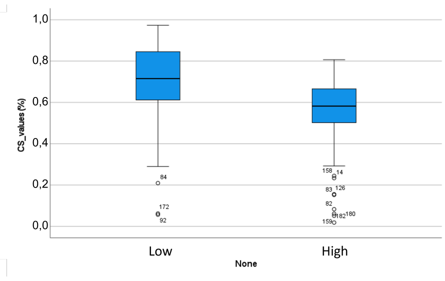
(a) Only car availability



(b) Only bicycle availability



(c) Both car and bicycle availability



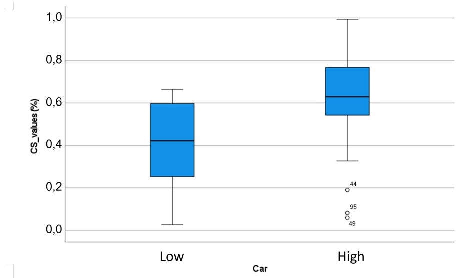
(d) Only by foot

Figure 8: The relation between vehicle ownership and CS-values based on non-western households

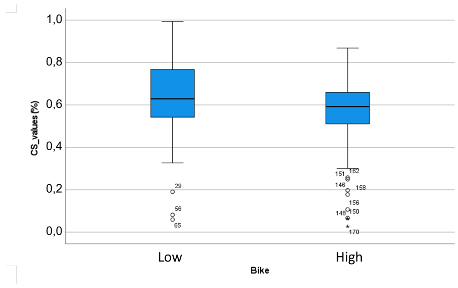
In the first plot of Figure 8, Figure 8a, it can be seen that for a higher percentage of people with only car availability, the CS values are lower. In the second plot, Figure 8b, the CS values are also lower for a higher percentage of people with only bike availability. This decrease is even higher than Figure 8a. In the third plot, Figure 8c, it can be seen that for higher percentages of people with both car and bike availability, the CS values are higher. Lastly, in the fourth plot, Figure 8d, it can be seen that for higher percentages of people with accessibility only by foot, the CS values are also lower. These correlations are also found for people with a non-western background in Figure 35.

7.1.4 Impact of modal split on the 10-minute accessibilities

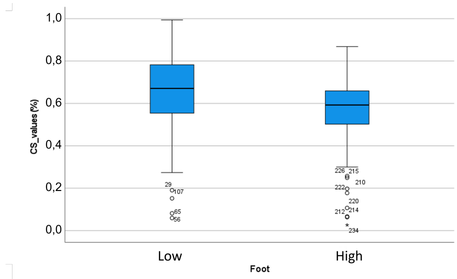
The impact of the modal split on the accessibility of 10 minutes in Overvecht and Kanaleneiland based on income has been plotted in Figure 9 into three graphs, one per transport mode usage. The plots based on the non-western background are shown in Figure 38, and the plots of the other socio-economic groups are shown in Figure 39 and Figure 40 (see Appendix E).



(a) Trips by car



(b) Trips by bike



(c) Trips by foot

Figure 9: The relation between transport mode usage and CS-values based on income

In Figure 9, three modes of transport, driving, cycling, and walking, are considered. In the first subplot, Figure 9a, it can be seen that higher car usage corresponds to higher CS values. The second subplot, Figure 9b, shows that higher bike usage corresponds to lower CS values. In the last subplot, Figure 9c, it can be seen that more walking also corresponds to lower CS values.

Looking at Figure 38, the differences based on the non-western background are less extreme. In all Subfigures, the range of CS values of high and low transport mode usage differs. In Figure 38a, the range is higher for low than for high car usage. In Figure 38b, the range is higher for high than low bike usage. In Figure 38c, the range is higher for a low amount of walking than for a high amount of walking. However, in Figure 38a, Figure 38b, and Figure 38c, the median is always the same. Therefore, there is little difference in CS values between low and high transport mode usage in all three cases.

7.1.5 Explanation of the relations between accessibility and socio-economic characteristics

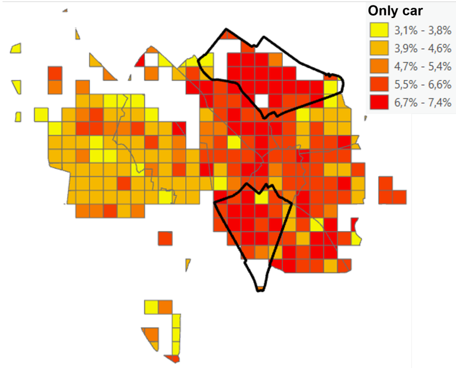
In Figure 4, it is shown that the CS values are low in areas with many non-western households and many households with a low income when modal availability is considered as a weighing factor of the accessibility values (see Section 6.3.2). These CS values are explained by Figure 5, which shows that the ownership of cars and bikes is lower in areas with many low-income and non-western households. Also, the percentage of households with only accessibility by foot is higher in these areas. Furthermore, in these areas, the ownership of only cars is higher. Also, in these areas, the ownership of only bikes is higher. Figure 8 and Figure 35 show that high ownership of only cars, high ownership of only bikes, low ownership of both cars and bikes, and high accessibility only by foot correspond to low CS values. Next, derived from Figure 5, car ownership, in general, is relatively low for low-income and non-western households. Also, bike ownership, in general, is relatively low for low-income and non-western households. Instead, accessibility only by foot for low-income and non-western households is relatively high. These relations show that the ownership of transport modes can explain the CS values of households with low-income and non-western backgrounds.

Figure 6 shows the CS values based on the modal split as a weighing measure of the accessibility values (see Section 6.3.3). The CS values are low in areas with many people with a low income which can be explained because car usage is lower for these people, as shown in Figure 7. Instead, according to Figure 7, people with a low-income cycle more and walk more. On the other hand, the difference between CS values in areas with many non-western people and those in other areas is less extensive. This outcome can be explained because car usage is higher in areas with many non-western people, as shown in Figure 7. Instead, in areas with many non-western people, bike usage is lower. Figure 9 shows that low car usage, high bike usage, and a high amount of walks correspond to lower CS values. On the other hand, high car and low bike usage correspond to higher CS values. These relations show that transport mode usage can explain the CS values of people with a low-income and non-western background.

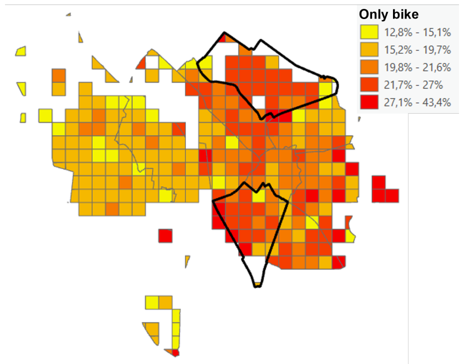
As mentioned in Section 1, the municipality of Utrecht aims to make destinations reachable within 10 minutes by bike and foot. Furthermore, if travel has to be made on a longer distance, this should be done by public transport. On the other hand, car ownership and usage do not fit in the 10-minute city. For people with a low income, this means that there is no 10-minute neighborhood lifestyle because of low bike ownership. Also, there is no 10-minute neighborhood lifestyle for non-western people because bike ownership and bike usage are low. Furthermore, this is because car usage is high. Although more destinations can be reached by car since car ownership and usage do not fit in a 10-minute city, car usage by non-western people should be reduced.

7.1.6 Vehicle ownership in several locations of Overvecht and Kanaleneiland

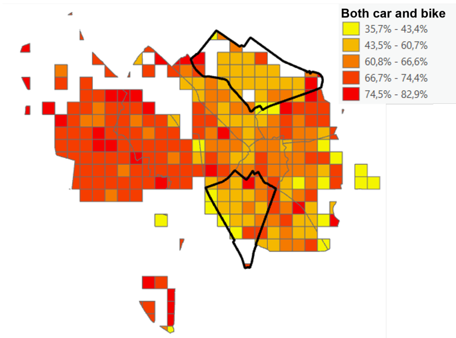
Now that the availability of transport modes is known for people with a low-income and non-western background, the impact of these values on Overvecht and Kanaleneiland can be determined. Some maps have been made based on the 500-by-500-meter grid. These are shown in Figure 10 for the income group. Figure 41 shows the grids for the non-western group. Figure 42 and Figure 43 show the grids for other socio-economic groups (see Appendix F).



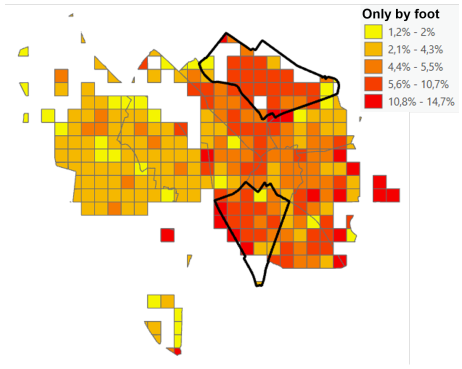
(a) Only car availability



(b) Only bicycle availability



(c) Both car and bicycle availability



(d) Only by foot

Figure 10: Vehicle ownership based on income

In all Subfigures of Figure 10, yellow means a relatively low percentage, and red means a relatively high percentage of each type of vehicle ownership. It can be seen that the legends of the Subfigures are different which is because the percentages of vehicle ownership differ per type, as shown in Figure 5. As shown in Figure 10a, the percentage of households with only cars in both Overvecht and Kanaleneiland is high compared to other areas in Utrecht, between 5,5 and 7,4%. On average, in Utrecht, this is 5,6%. The percentage of households owning only bikes is, as shown in Figure 10b, also reasonably high, compared to other parts of Utrecht. In a big part of Overvecht and Kanaleneiland, this is between 21,7 and 27%, while on average, in Utrecht, this is 22,1%. As shown in Figure 10c, the percentage of households owning both cars and bicycles is lower in both areas. In many parts of Overvecht and Kanaleneiland, this is between 43,5 and 60,7%, while on average, in Utrecht, this is 66,2%. Lastly, as shown in Figure 10d, the percentage of households with no availability of transport modes is higher compared to other parts of Utrecht, mostly between 5,6 and 10,7%. On average, in Utrecht, this is 6%.

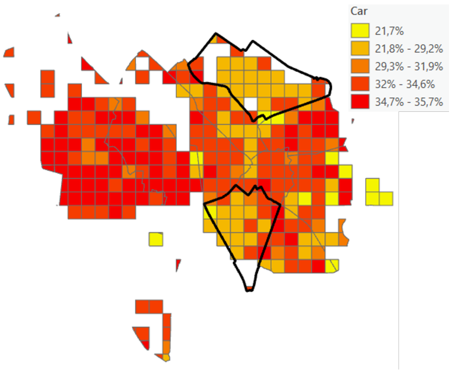
For people with a non-western background, it is comparable to people with a low income. The percentage of only car ownership is relatively high in Overvecht and Kanaleneiland compared to other parts of Utrecht. It usually is between 6.4 and 9.1%, while on average, in Utrecht, this is 5,5%. The percentage of households with only bike ownership is also higher than other areas, generally between 26,3 and 28,2%. On average, in Utrecht, this is 25,6%. The percentage of car and bike ownership usually is between 47,6 and 58%, which is low compared to other areas in Utrecht. On average, in Utrecht, it is 61,2%. Lastly, the percentage of households without the ownership of transport modes is high compared to other areas, generally between 9 and 15%. On average, in

Utrecht, this is 7,6%.

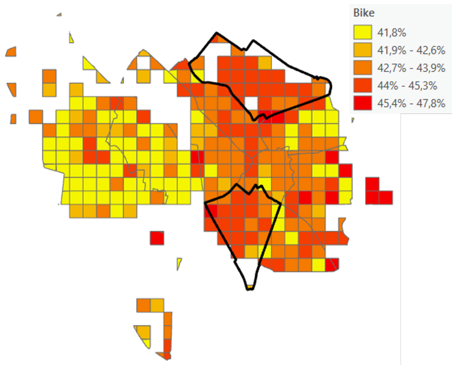
In conclusion, the extent to which people with a low-income and non-western background own vehicles is also visible in Overvecht and Kanaleneiland. Ownership of only cars, ownership of only bikes, and accessibility only by foot are high. Moreover, the availability of cars and bikes is low.

7.1.7 Usage of transport modes in several locations of Overvecht and Kanaleneiland

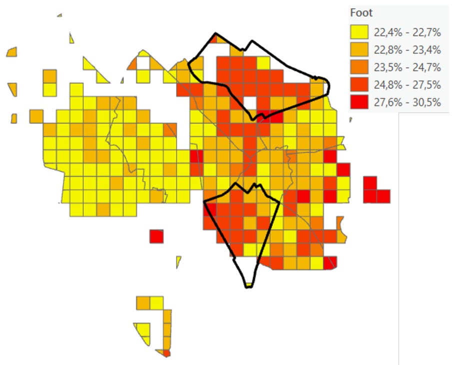
The usage of transport modes is known for people with a low income and non-western background, so now the impact of these values on Overvecht and Kanaleneiland can be discovered. Some maps have been made based on the 500-by-500-meter grid. Figure 11 shows, for the income group, for several locations in Utrecht in percentages, how regularly each transport mode is used. For the non-western group, this is shown in Figure 44, and for the other socio-economic groups, these are shown in Figure 45 and Figure 46 (see Appendix G).



(a) Travelling by car



(b) Travelling by bike



(c) Travelling by foot

Figure 11: Transport mode usage based on income

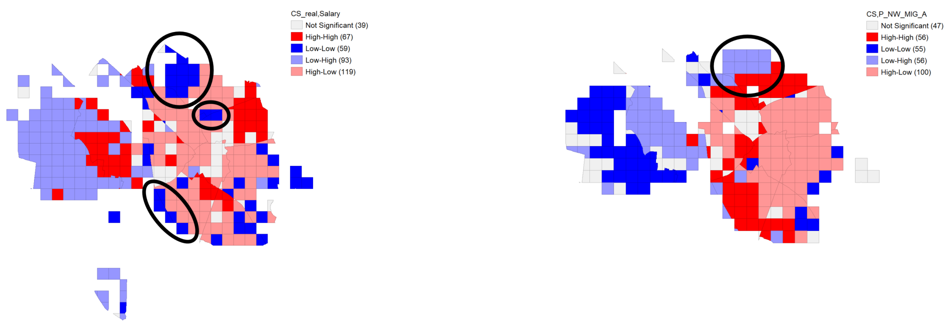
Also, in Figure 11, it can be seen that the legends of the Subfigures are different. This difference in legends is because the percentages of transport mode usage differ per type, as shown in Figure 7. As shown in Figure 11a, the percentage of car usage in both Overvecht and Kanaleneiland is low compared to other areas in Utrecht, between 21,8 and 29,2%. On average, in Utrecht, this is 32,5%. The percentage of bike usage is, as shown in Figure 11b, high compared to other parts of Utrecht. In a big part of Overvecht and Kanaleneiland, this is between 44 and 45,3%, while on average, in Utrecht, this is 43,4%. As shown in Figure 11c, the percentage of walking is also higher in both areas. In many parts of Overvecht and Kanaleneiland, this is between 24,8 and 27,5%, while on average, in Utrecht, this is 24,0%.

It is different for people with a non-western background from people with a low income, as shown in Figure 44. According to Figure 44a, the percentage of car usage is relatively high in Overvecht and Kanaleneiland compared to other parts of Utrecht. It usually is between 41,5 and 43,6%, while on average, in Utrecht, this is 41,3%. According to Figure 44b, the percentage of households with bike usage is lower than in other areas, generally between 36,6 and 39,6%. On average, in Utrecht, this is 40,6%. The percentage of walking usually is, according to Figure 44c, between 18,5 and 19,7%, which is high compared to other areas in Utrecht. On average, in Utrecht, this is 18,0%.

In conclusion, the usage of transport modes for people with a low-income and non-western background is also visible in Overvecht and Kanaleneiland. Looking at low-income people, the amount of driving is low, and the amount of cycling and walking is high. Looking at non-western people, the amount of driving is high, the amount of cycling is low, and the amount of walking is high.

7.1.8 Subquestion 1: The influence of individual aspects on the 10-minute accessibility in Overvecht and Kanaleneiland with accessibility values weighed by modal availability

Now that the relationship between the socio-economic characteristics, on the one hand, and the CS values and the vehicle ownership, on the other hand, is known, the influenced locations in Overvecht and Kanaleneiland can be determined. Figure 12 shows for each 500-by-500 meter area in Utrecht what the cluster is between the CS value and socio-economic characteristic, based on modal availability as weighing measure of the accessibility values, explained in Section 6.3.2. For the other socio-economic groups, the clusters can be seen in Figure 47 in Appendix H.



(a) Income of people

(b) People with non-western background

Figure 12: The clusters between accessibility weighed by modal availability and socioeconomic characteristics

These clusters are made using Bivariate Local Moran's I as explained in Section 6.5. In all Subfigures of Figure 12, the colors have the following meaning:

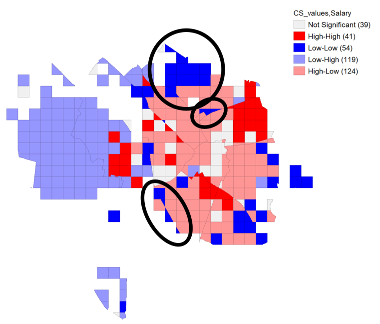
- Dark-blue means a low CS value and a low amount of the socio-economic group.
- Light-blue means a low CS value and a high amount of the socio-economic group.
- Dark-red means a high CS value and a high amount of the socio-economic group.
- Light-red means a high CS value and a low amount of the socio-economic group.

Some relations between CS values and socio-economic groups can be seen in Figure 12. Firstly, it can be seen in Figure 12a that there are many low-low clusters in the northwest of Overvecht and the west of Kanaleneiland: CS values and income of households are low. In Figure 12b, it can be seen that in the northwest of Overvecht, there are many low-high clusters: the CS values are low, and the number of households with a non-western background is high.

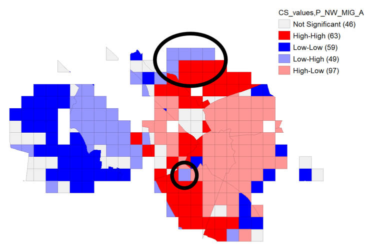
As explained in Section 7.1.5, for people with a low-income and non-western background, the percentage with only car ownership, only bike ownership, and only accessibility by foot is relatively high on the one hand. On the other hand, the percentage of both car and bike ownership is relatively low. Also explained in Section 7.1.5 is that these relations correspond to low CS values. Next, Section 7.1.5 explains that car ownership in general for these socioeconomic groups is relatively low, bike ownership, in general, is relatively low, and accessibility only by foot is high. These relations declare why low-low clusters are found for low-income residents northwest of Overvecht and west of Kanaleneiland. Also, these relations declare why low-high clusters are found for non-western residents northwest of Overvecht. However, although the same pattern of vehicle ownership is found in almost the whole of Overvecht and Kanaleneiland, as shown in Figure 10 in many parts, high CS values have been found. So vehicle ownership does not affect all areas of Overvecht and Kanaleneiland in the same way.

7.1.9 Subquestion 1: The influence of individual aspects on the 10-minute accessibility in Overvecht and Kanaleneiland with accessibility values weighed by modal split

Now that the relationship between the socio-economic characteristics, on the one hand, and the CS values and the usage of transport modes, on the other hand, is known, the influenced locations in Overvecht and Kanaleneiland can be determined. Figure 13 shows for each 500-by-500 meter area in Utrecht the cluster between the CS values and the socio-economic characteristics, based on modal split as weighing measure of the accessibility values, explained in Section 6.3.3. For the other socio-economic groups, the clusters can be seen in Figure 48 in Appendix I.



(a) Income of people



(b) People with non-western background

Figure 13: The clusters between accessibility weighed by modal split and socioeconomic characteristics

Also, in Figure 13, low-low clusters for low-income people are found in the northwest of Overvecht and the west of Kanaleneiland. Next, low-high clusters for non-western people are found in the northwest of Overvecht. However, some differences exist between Figure 13 and Figure 12 for both socio-economic groups. In the case of income, in Overvecht, more low-low clusters have been found in Figure 13a, compared to Figure 12a, which means that more low-low clusters are found when considering the usage of transport modes instead of ownership of vehicles. This result is found because car usage is lower compared to car ownership. Thus, CS values are lower considering transport mode usage instead of vehicle ownership. On the other hand, where in Figure 12a some low-low clusters have been found in the west of Kanaleneiland, in Figure 13a less of these clusters have been found, which means that in the west of Kanaleneiland, less low-low clusters are found when considering the usage of transport modes instead of vehicle ownership. The reason behind this is unclear.

Figure 13b shows low-high clusters for people with a non-western background northwest of Overvecht. There are fewer of these clusters compared to Figure 12b, which means there are fewer high-low clusters when considering the usage of transport modes instead of vehicle ownership. This result is found because there is more car usage than car ownership. Therefore, higher CS values are found.

7.2 Subquestion 2: Relation between accessibility and spatial aspects

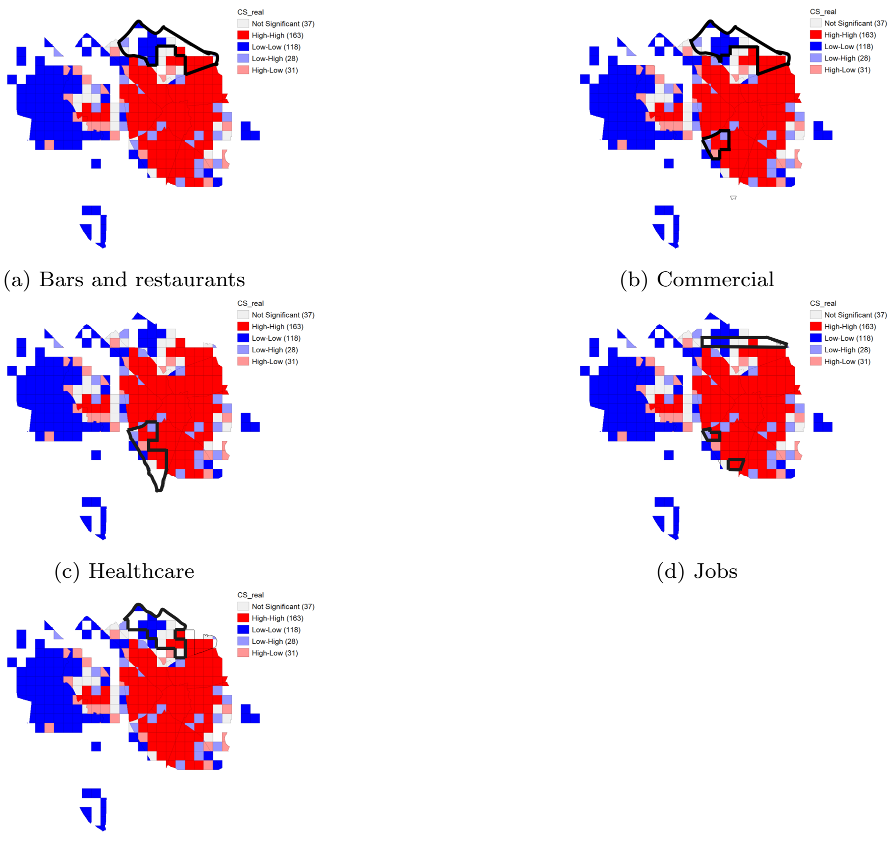
Next to the relationship between the CS values and socio-economic groups, the relations between the CS values and the distribution of services have been investigated. The percentage of each socio-economic group having sufficient accessibility within 10 minutes to each destination type is shown in Table 4. These values are based on the minimum required number of services per destination type that should be accessible as shown in Table 3 in Section 6.6.

Table 4: Percentage of accessibility to destination types per socio-demographic group

	Non-western background		Low income		Benefits before state pension age		Oneparent households	
	Ov	Ka	Ov	Ka	Ov	Ka	Ov	Ka
Bars and restaurants	51,4	96,1	57,8	96,6	51,8	96,4	52,6	98,0
Elementary- and secondary schools	100,0	99,9	99,9	100,0	99,8	99,8	100,0	100,0
Commercial	53,7	56,9	59,9	56,4	53,7	65,2	54,3	68,8
Entertainment	82,0	81,6	87,4	85,3	81,8	85,1	82,8	87,0
Food	90,3	99,3	91,6	99,4	89,7	99,2	90,2	100,0
Jobs	76,2	72,4	75,3	75,4	77,0	78,2	77,5	79,8
Healthcare	84,5	71,9	82,3	71,7	81,8	77,9	81,1	81,8
Parks	100,0	99,9	100,0	100,0	100,0	99,8	100,0	100,0
Public transport	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
Recreation	98,5	99,3	98,8	100,0	96,9	99,1	96,2	98,4
Sports	78,9	100,0	81,2	100,0	79,9	100,0	78,0	100,0

Looking at Table 4, for some socio-economic characteristics in Overvecht and Kanaleneiland, the accessibility to some of the destinations is lower than 80%, which was the threshold set in Section 6.6. Considering this threshold, in Overvecht, almost all socio-economic groups have low accessibility within 10 minutes to bars and restaurants, commercial destinations, jobs, and sports facilities. Next, almost all socio-economic groups in Kanaleneiland have low accessibility within 10 minutes to commercial destinations, jobs, and healthcare destinations.

Knowing what the destinations with low accessibility are, the parts of Overvecht and Kanaleneiland with a low number of destinations and low accessibility to destinations have been determined, which is shown in Figure 14. Since the destination types with low accessibility are almost the same for all socio-economic groups and since Figure 12 showed that the low CS values were found in the northwest of Overvecht and the west of Kanaleneiland for all groups, it is assumed that these clusters are the same for all socio-economic groups. Furthermore, it is assumed that the locations with CS values weighed by modal availability (Section 6.3.2) and those weighed by modal split (Section 6.3.3) are the same. Therefore, the CS values are only calculated based on accessibility values weighed by modal availability.



(a) Bars and restaurants

(b) Commercial

(c) Healthcare

(d) Jobs

(e) Sports

Figure 14: The clusters between accessibility and distribution of services

As shown in Figure 14, for each destination type, the clusters have been determined for each 500-by-500 meter area. The black lines show the areas with fewer services accessible within 1 kilometer than the thresholds shown in Table 3 in Section 6.6. In Overvecht, there is a lack of bars/restaurants and commercial destinations in the northern part. Furthermore, there is a lack of jobs in the center of Overvecht. Lastly, there is a lack of sports facilities in most parts of Overvecht. In Kanaleneiland, there is a lack of commercial destinations in the northwest. Healthcare destinations are mostly lacking in the west of Kanaleneiland. Lastly, jobs are lacking in the northwest and south of Kanaleneiland. It can be seen that the locations with low CS values and low amount of destinations are approximately the same as in Figure 12, namely the areas northwest of Overvecht and west of Kanaleneiland. So a lack of destinations is found in a more extensive part of Overvecht and Kanaleneiland, but this does not always mean low CS values. Therefore, the lack of destinations does not affect the CS values in these areas in the same way.

8 Conclusion

The main conclusion derived from this thesis is that many residents with a low income and a non-western background in Overvecht and Kanaleneiland cannot reach all services within 10 minutes. Therefore, many of these people do not have a 10-minute neighborhood lifestyle, so an improvement in 10-minute accessibility in this area is needed if the municipality of Utrecht wants to reach the goal of a 10-minute city. The lack of the 10-minute neighborhood lifestyle is primarily because of vehicle ownership and transport mode usage. In areas with many residents with a low income, bike ownership is lower than in other areas. In areas with many residents with a non-western background, bike ownership is also lower compared to other areas. Next, car usage is high in these areas for non-western people, so accessibility to services increases. However, since the municipality of Utrecht wants accessibility of 10 minutes by foot and bike, car usage does not fit the ideal of the 10-minute city. This lack of vehicle ownership and transport mode usage mainly affects CS values northwest of Overvecht and west of Kanaleneiland. So if the municipality of Utrecht wants to reach the goal of a 10-minute city, bike ownership should be stimulated. Also, cycling should be stimulated, and driving should be discouraged, especially among non-western people. The lack of the 10-minute neighborhood lifestyle is also because of a lack of some destinations in the area. In Overvecht, there is a lack of bars/restaurants, commercial destinations, jobs, and sports facilities within 10 minutes of traveling. In Kanaleneiland, there is a lack of commercial destinations, healthcare destinations, and jobs. Again, this is most visible in the northwest of Overvecht and the west of Kanaleneiland. If the municipality of Utrecht wants to reach the goals of a 10-minute city, the connection to these services from these areas should be improved.

9 Discussion and recommendations for further research

Some factors in the BSc thesis have led to restrictions and uncertainties. There are uncertainties in vehicle ownership, transport mode usage, and the importance of trips since those have not been calculated based on people living in the areas themselves. The data on this level was limited, so it has been decided to make a distinction based on socio-economic characteristics. However, the outcomes can differ in the areas of Overvecht and Kanaleneiland. There are also uncertainties in vehicle ownership, transport mode usage, and the importance of trips since the information in the datasets of Dat.mobility, OVIN, and ODIN are based on a selection of inhabitants rather than all inhabitants. This uncertainty is even higher given that vehicle ownership and transport mode usage are based on different sources (Dat.mobility, OVIN, and ODIN). Because of these uncertainties, there should be more research on vehicle ownership, transport mode usage, and important destinations in Overvecht and Kanaleneiland. Also, it is interesting to carry out interviews as a follow-up study which should provide more insights into why low-income and non-western people in Overvecht and Kanaleneiland do not have a 10-minute neighborhood lifestyle. Also, this should provide more inside into the reasons behind their choices in vehicle ownership and usage of transport modes. A literature study on the interview of Durand et al. (2023) explained in Section 6.7 has attempted to get more inside. One of these insights is that roads are often dangerous and that cycling lanes are often unclear. Something else is that there is a language barrier for some residents with a non-western background. Lastly, according to the report, residents with a non-western background are afraid that their bikes will be stolen. However, the interview outcomes are not based on Overvecht and Kanaleneiland. Also, the focus lies on people with a non-western background and less on people with a low income. Therefore, the reasons behind accessibility can be different. A follow-up study could be done to research the importance of the insights given in this report on Overvecht and

Kanaleneiland and to give solutions to improve the 10-minute neighborhood lifestyle based on these insights. Also, it is not sure which destinations are relevant to people with a low-income and non-western background and which destinations they would use if accessibility were higher than now. Next to this uncertainty, there should also be more research on other socio-economic groups. In this research, the focus has been on people with a low income and people with a non-western background; however, less focus has been put on people with benefits below state pension age and people from one-parent households. Also, there should be other interesting socio-economic groups not considered in this report. Another uncertainty is that it has been mentioned that public transport is well-accessible for all locations in Overvecht and Kanaleneiland; however, the schedule has not been considered. Also, the intensity of car traffic changes over time which has not been considered. So these differences in time and, thus, differences in accessibility should be considered in the following research. Another uncertainty is that in Kanaleneiland, car usage is lower than car availability but that the accessibility weighed by modal split is higher than by modal availability. Subsequent uncertainty is that it is unclear why there is not much difference in CS values between low and high values for non-western people (see Figure 38). The last uncertainty is based on the comparison with MapItOut: it is questionable if the assumption should have been made that the isochrones of ArcGIS should be comparable to the isochrones of MapItOut since the factors on which MapItOut are based are uncertain. It is especially questionable for the isochrones of cars where the maximum speed on the road has been considered instead of the average speed driven on each road. Therefore, the isochrones of ArcGIS were more extensive than the isochrones of MapItOut. Thus, the size of the isochrones of ArcGIS was reduced to the size of the isochrones of MapItOut. However, it is still unsure if the isochrones of ArcGIS should have the same size as the isochrones of MapItOut.

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Appendices

A Verification of the service areas

For the verification, in both Overvecht and Kanaleneiland, six points spread over the areas will be selected from ArcGIS, three in Overvecht and three in Kanaleneiland, and the addresses of these points will be entered in the "MapItOut" tool. For car, bicycle, and pedestrians, a comparison between the reachable areas of ArcGIS and MapItOut will be made. Since it is not possible in MapItOut to determine the areas for 10 minutes, the comparison will be based on 15-minute areas. If the extent of the areas in ArcGIS is in line with the extent of the areas of MapItOut, it means that the reachable areas of ArcGIS are accepted and the Network Analysis can be used for further steps.

The chosen intersections for comparison are shown in Table 5 and Figure 15.

Table 5: Neighbourhoods verification

Neighbourhood	**Intersection**
Overvecht	Franciscusdreef/Rio Brancodreef
	Rio Negrodreef/Carnegiedreef
	Marnedreef/Moezeldreef
Kanaleneiland	Overste den Oudenlaan/Koningin Wilhelminalaan
	Winthontlaan/Eendrachtlaan
	Columbuslaan/Afrikalaan

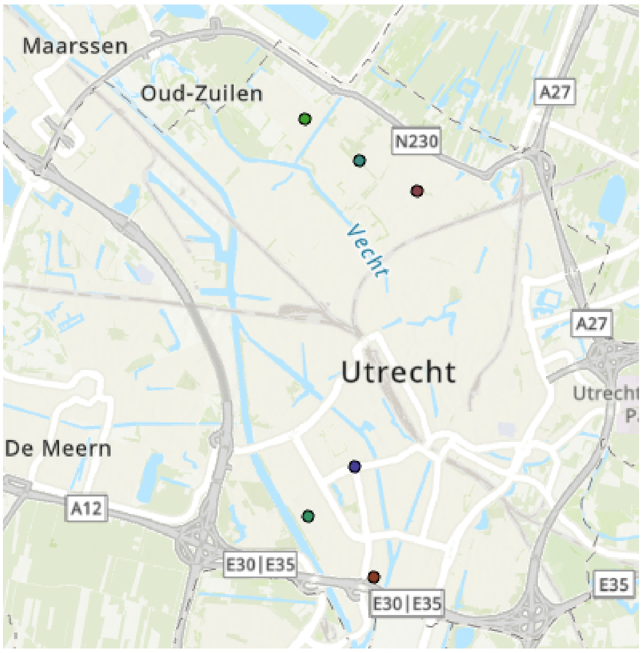


Figure 15: Locations for verification

As can be seen in the Figure, the intersections used for the verification have been chosen such that they are spread over the two areas.

During the verficiation of the Service Areas, it has been determined to which extent the areas are similar and if they are acceptible for the analysis of the accessibility of services. An example will be shown on the hand of intersection Franciscusdreef/Rio Brancodreef with the Service Area of a bicycle. This is shown in Figure 16.

Figure 16: Intersection Franciscusdreef/Rio Brancodreef bicycle

As can be seen in the Figure, the extension of both Service Areas are quite similar. Firstly, in both areas, on the north side it is possible to cycle within 10 minutes to Westbroek. Also, it is possible in both areas to cycle within this time to a location nearby Groenekan, just before the highway. Furthermore, in both areas the Amsterdamsestraatweg in the southwest part of the Service Area can be reached within 10 minutes. Lastly, it is also possible to reach within this time the Molenpolder. So this is an example of a Service Area which is verified as acceptible.

In general, the Service Areas of the bicycles and pedestrians have been verified already on the first try. For the cars, however, it turned out that the Service Areas of ArcGIS reached further than the Service Areas of MapItOut. Therefore, it has been decided to increase the travel time on each line segment for the car. It has been decided to increase the travel time to 1.5 times the travel time, except from highways where the travel time has been increased to 1.8 times the travel time. The verifications of all Service Areas can be found in Figure 17 to Figure 34.

A.1 Cars

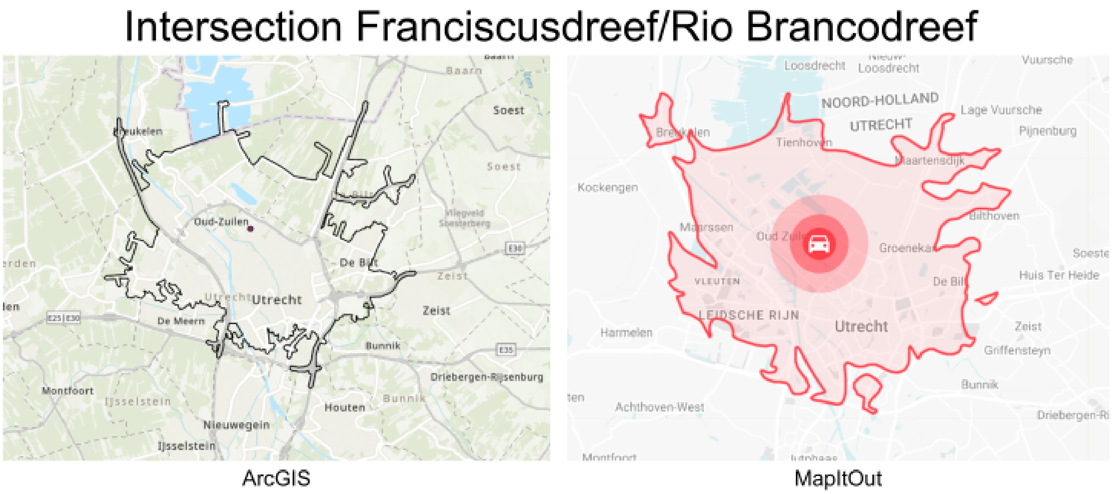


Figure 17: Intersection Franciscusdreef/Rio Brancodreef car

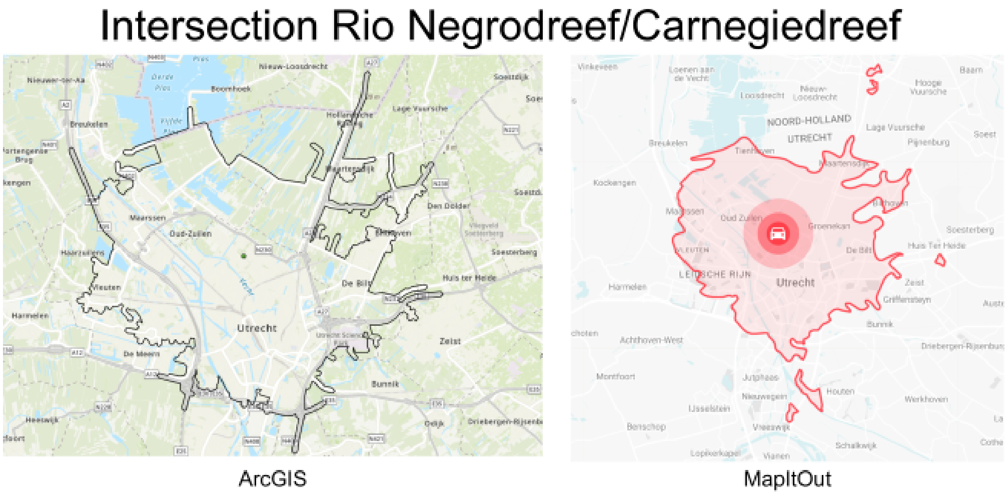


Figure 18: Intersection Rio Negrodreef/Carnegiedreef car

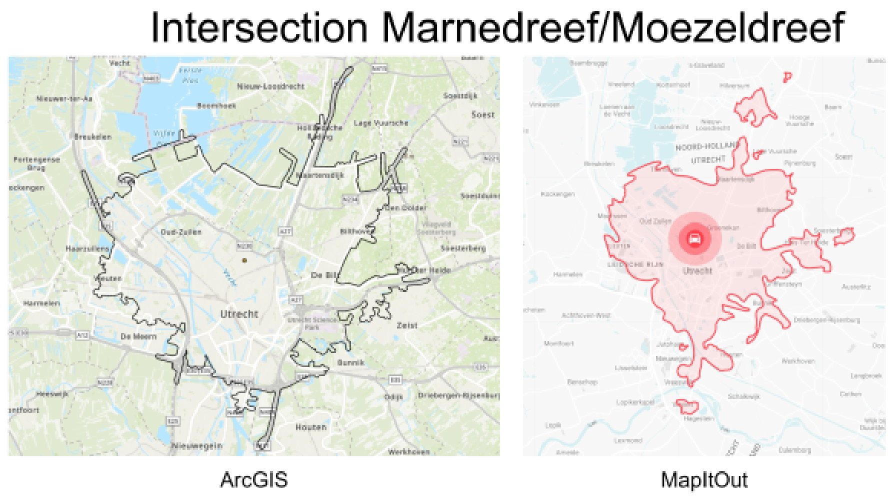


Figure 19: Intersection Marnedreef/Moezeldreef car

Figure 20: Intersection Overste den Oudenlaan/Koningin Wilhelminalaan car

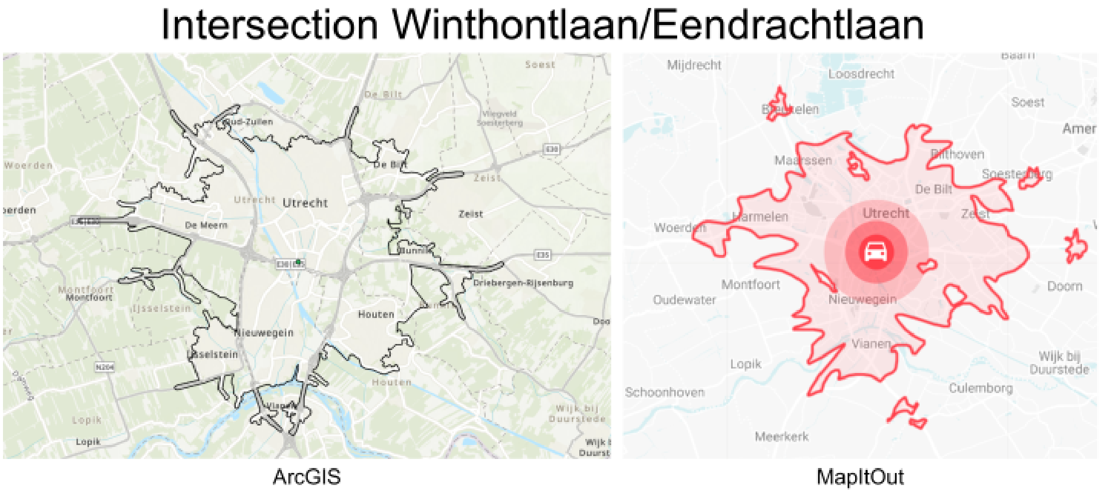


Figure 21: Intersection Winthontlaan/Eendrachtlaan car

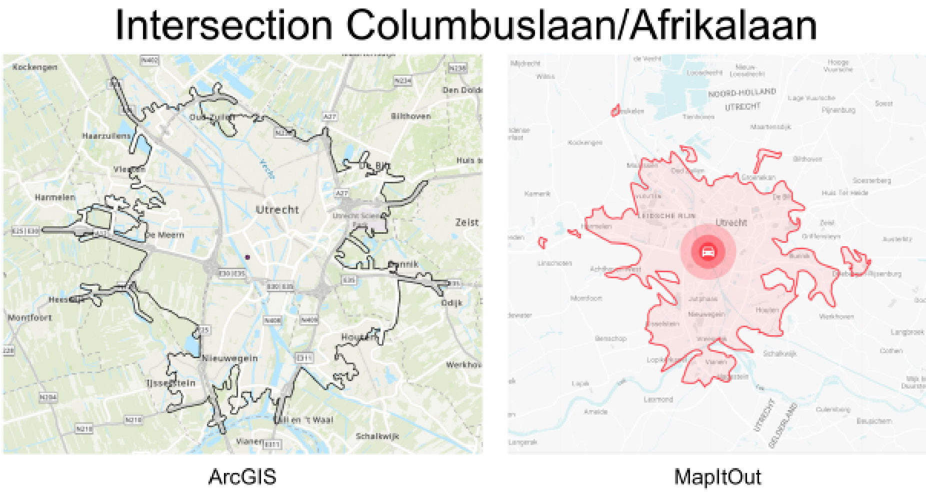


Figure 22: Intersection Columbuslaan/Afrikalaan car

A.2 Bicycles

Figure 23: Intersection Franciscusdreef/Rio Brancodreef bicycle

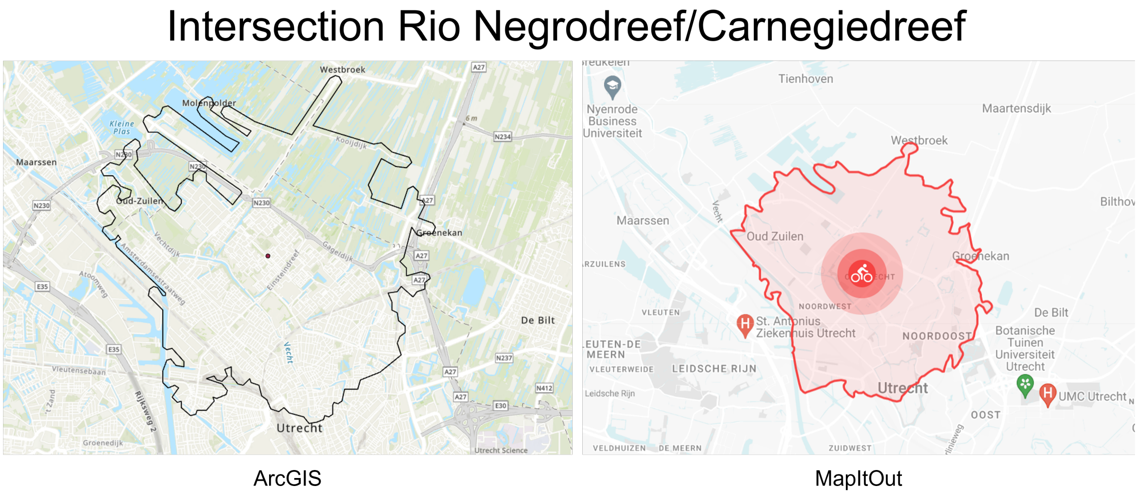


Figure 24: Intersection Rio Negrodreef/Carnegiedreef bicycle

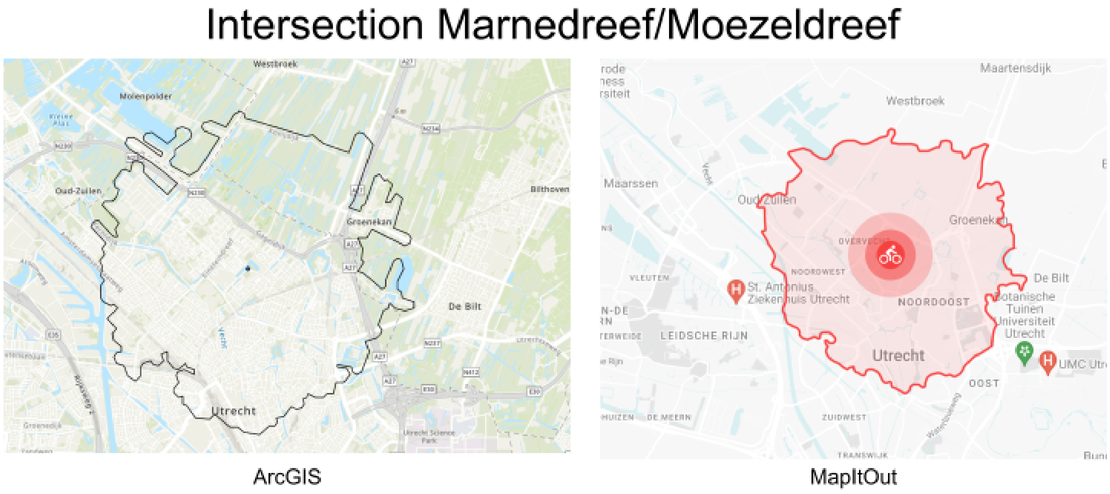


Figure 25: Intersection Marnedreef/Moezeldreef bicycle

Figure 26: Intersection Overste den Oudenlaan/Koningin Wilhelminalaan bicycle

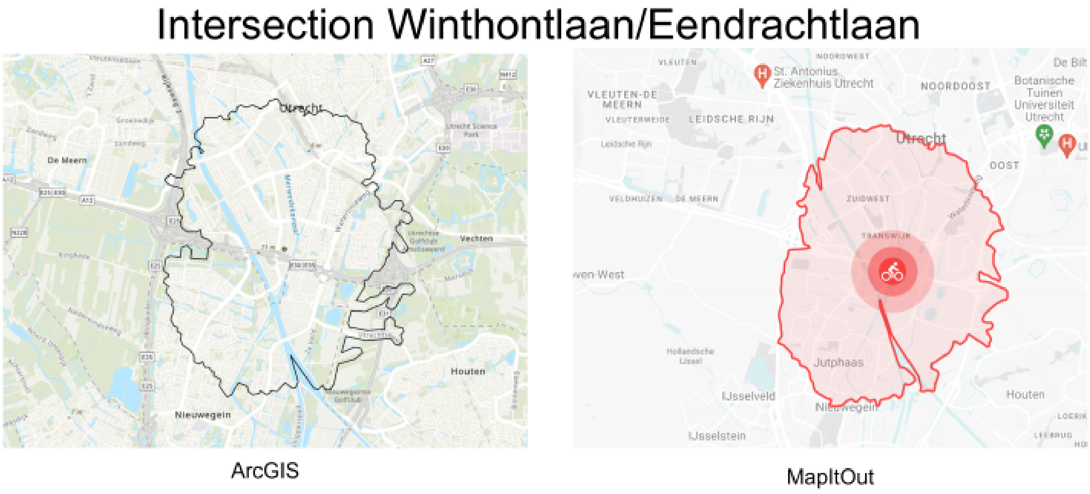


Figure 27: Intersection Winthontlaan/Eendrachtlaan bicycle

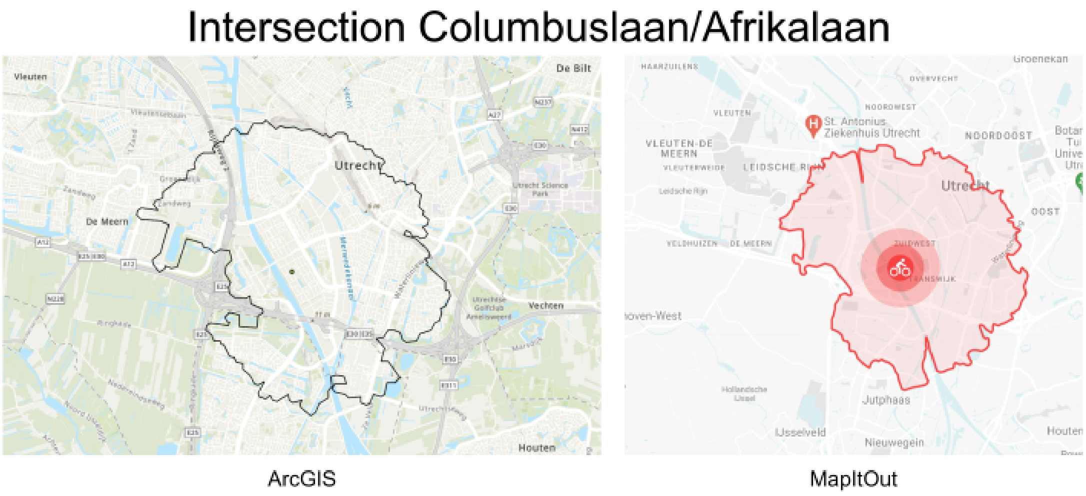


Figure 28: Intersection Columbuslaan/Afrikalaan bicycle

A.3 Pedestrians

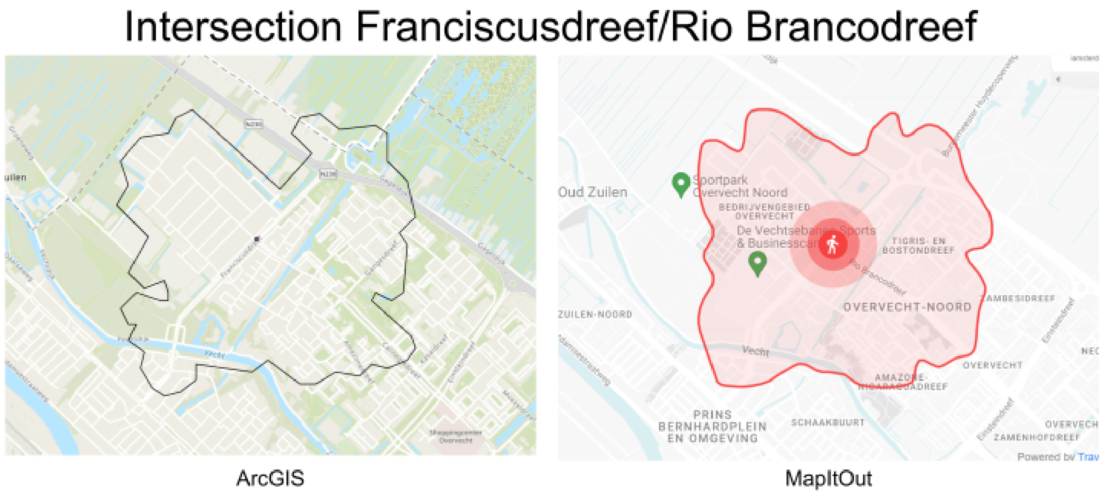


Figure 29: Intersection Franciscusdreef/Rio Brancodreef pedestrians

Figure 30: Intersection Rio Negrodreef/Carnegiedreef pedestrians

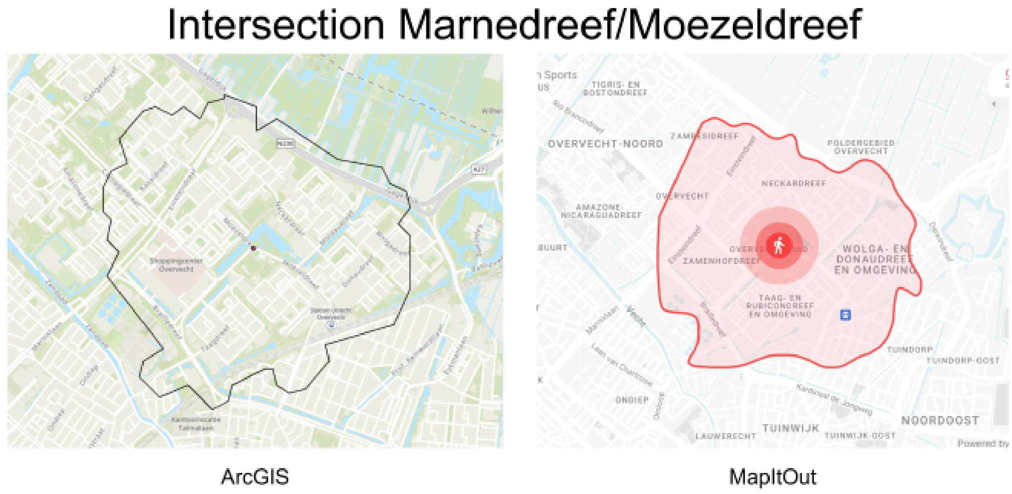


Figure 31: Intersection Marnedreef/Moezeldreef pedestrians

Figure 32: Intersection Overste den Oudenlaan/Koningin Wilhelminalaan pedestrians

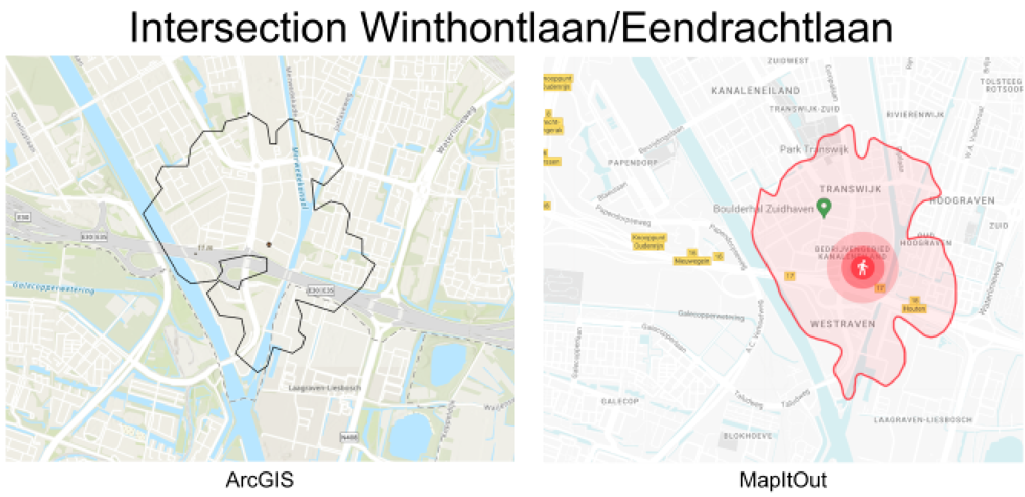


Figure 33: Intersection Winthontlaan/Eendrachtlaan pedestrians

Figure 34: Intersection Columbuslaan/Afrikalaan pedestrians

B Weights of the destination types

B.1 Weights of the destination types based on income

Table 6: Weights of the destination types based on income

Income	00-20 low income	20-40 below middle income	40-60 middle income	60-80 above middle income	80-100 high income	00-40 low to below middle income	20-60 below middle to middle income	40-80 middle to above middle income	60-100 above middle to high income
Bars and restaurants	3,8%	3,3%	3,3%	3,4%	4,9%	3,4%	3,3%	3,3%	4,3%
Colleges and universities	1,1%	0,9%	0,6%	0,4%	0,8%	0,9%	0,8%	0,5%	0,7%
Commercial	1,5%	1,9%	2,5%	2,3%	1,6%	1,8%	2,2%	2,4%	1,9%
Elementary and secondary schools	10,4%	10,7%	12,2%	14,7%	17,6%	10,6%	11,4%	13,3%	16,4%
Entertainment	3,1%	3,0%	3,9%	3,9%	4,0%	3,0%	3,4%	3,9%	3,9%
Food	18,9%	20,2%	19,6%	18,4%	18,3%	19,9%	19,9%	19,0%	18,4%
Healthcare	0,7%	0,8%	0,6%	0,5%	0,3%	0,8%	0,7%	0,6%	0,4%
Jobs	20,9%	26,0%	26,8%	25,9%	19,3%	24,6%	26,4%	26,4%	21,9%
Parks	3,1%	3,1%	2,4%	2,4%	3,1%	3,1%	2,8%	2,4%	2,8%
Public transport	32,0%	25,8%	23,2%	22,6%	22,4%	27,5%	24,5%	22,9%	22,5%
Recreation	0,9%	1,1%	0,9%	1,1%	1,7%	1,0%	1,0%	1,0%	1,5%
Sports	3,7%	3,2%	4,0%	4,4%	6,1%	3,3%	3,6%	4,2%	5,4%

B.2 Weights of destination types for residents with non-western background and from one-parent households

Table 7: Weights of the destination types for residents of non-western background and one-parent households

Non-western background	Weight of destination types (%)
Bars and restaurants	3,8%
Colleges and universities	0,7%
Commercial	2,0%
Elementary and secondary schools	13,7%
Entertainment	3,6%
Food	19,1%
Healthcare	0,6%
Jobs	23,8%
Parks	2,8%
Public transport	24,2%
Recreation	1,2%
Sports	4,5%

B.3 Weights of destination types based on benefits below state pension age

Table 8: Weights of the destination types based on benefits below state pension age

Non-western background	Weights for people with benefits	Weights for people without benefits
Bars and restaurants	3,7%	3,7%
Colleges and universities	0,1%	0,8%
Commercial	2,1%	1,9%
Elementary and secondary schools	14,6%	13,2%
Entertainment	3,6%	3,6%
Food	26,2%	19,5%
Healthcare	1,5%	0,6%
Jobs	16,5%	23,6%
Parks	4,5%	2,8%
Public transport	22,3%	24,6%
Recreation	0,9%	1,3%
Sports	4,1%	4,3%

C Assumptions of low- and high values of modal availability and modal split

C.1 Modal availability

The box plots in Figure 8 are made based on income. The low and high values in the graphs correspond to the low and high values of modal availability. For the availability of only cars, it has been assumed that low values are lower than or equal to 4% and high values are higher than or equal to 6%. Low values are assumed to be lower than or equal to 20% for the availability of only bikes, and high values are assumed to be higher than or equal to 35%. For the availability of both cars and bikes, low values are assumed to be lower than or equal to 50%, and high values are assumed to be higher than or equal to 70%. Lastly, for availability only by foot, low values are assumed to be lower than or equal to 5%, and high values are assumed to be higher than or equal to 10%.

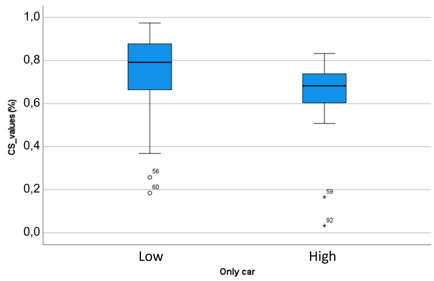
The same has been done in Figure 35 based on non-western background. For the availability of only cars, it has been assumed that low values are lower than or equal to 5% and high values are higher than or equal to 7%. Low values are assumed to be lower than or equal to 26% for the availability of only bikes, and high values are assumed to be higher than or equal to 37%. For the availability of cars and bikes, low values are assumed to be lower than or equal to 55%, and high values are assumed to be higher than or equal to 62%. Lastly, for accessibility only by foot, low values are assumed to be lower than or equal to 7%, and high values are assumed to be higher than or equal to 9%.

C.2 Modal split

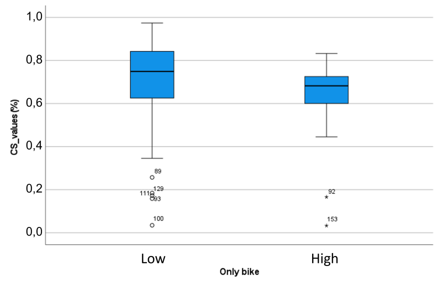
Also, in Figure 9, it can be seen that box plots are made based on income. These graphs' low and high values correspond to the modal split's low and high values. For driving, it has been assumed that low values are lower than or equal to 29% and high values are higher than or equal to 34%. For cycling, low values are assumed to be lower than or equal to 43%, and high values are assumed to be higher than or equal to 44%. For walking, low values are assumed to be lower than or equal to 24%, and high values are assumed to be higher than or equal to 26%.

The box plots in Figure 38 are made based on non-western backgrounds. These graphs' low and high values correspond to the modal split's low and high values. For driving, it has been assumed that low values are lower than or equal to 41% and high values are higher than or equal to 42%. For cycling, low values are assumed to be lower than or equal to 39%, and high values are assumed to be higher than or equal to 41%. For walking, low values are assumed to be lower than or equal to 18%, and high values are assumed to be higher than or equal to 19%.

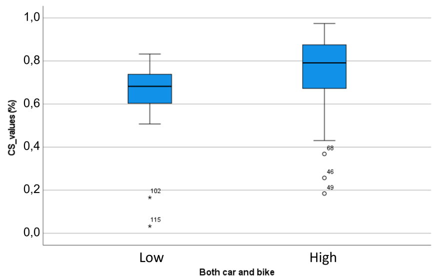
D Relation between accessibility and modal availability



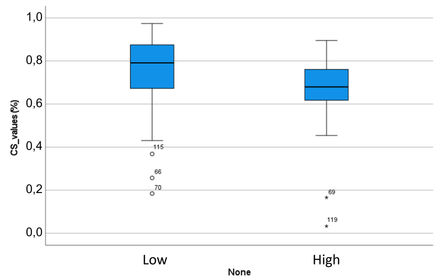
(a) Only car availability



(b) Only bicycle availability

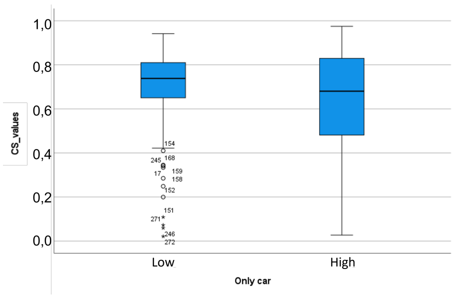


(c) Both car and bicycle availability

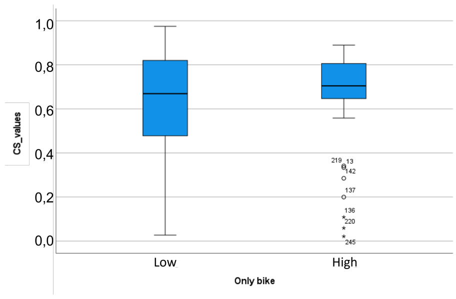


(d) Availability only by foot

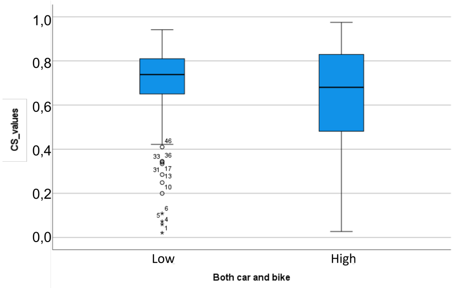
Figure 35: The relation between vehicle ownership and CS-values based on non-western background



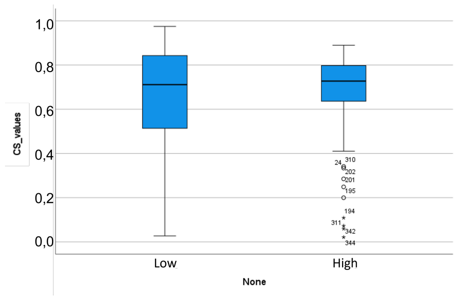
(a) Only car availability



(b) Only bicycle availability

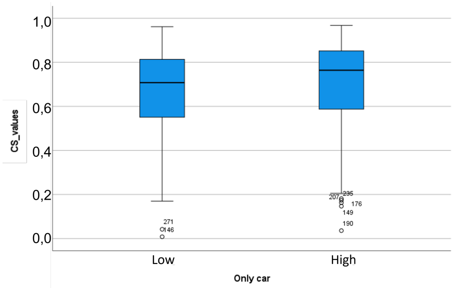


(c) Both car and bicycle availability

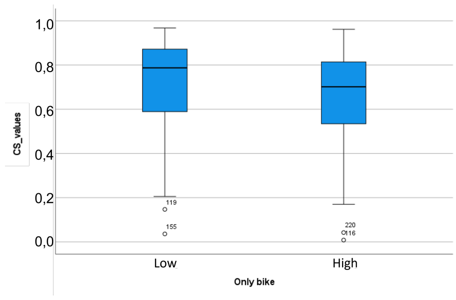


(d) Availability only by foot

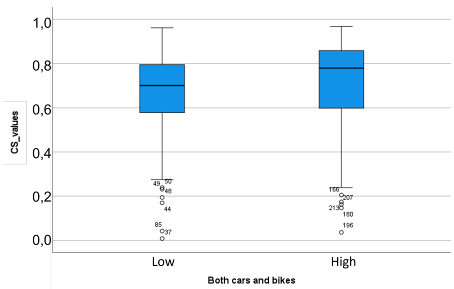
Figure 36: The relation between vehicle ownership and CS-values based on households with benefits below state pension age



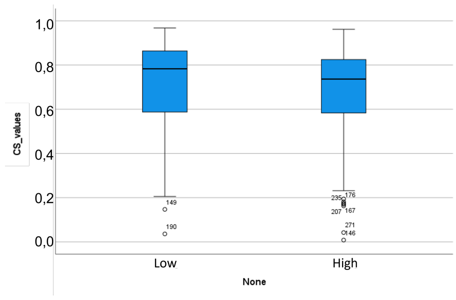
(a) Only car availability



(b) Only bicycle availability



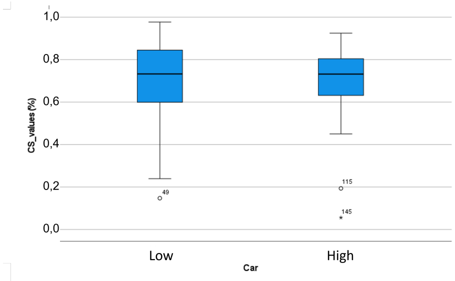
(c) Both car and bicycle availability



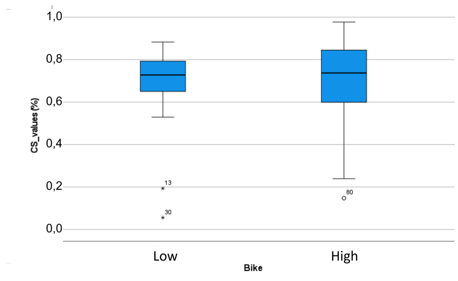
(d) Availability only by foot

Figure 37: The relation between vehicle ownership and CS-values based on one-parent households

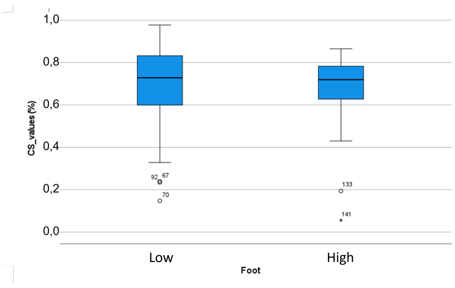
E Relation between accessibility and modal split



(a) Trips by car

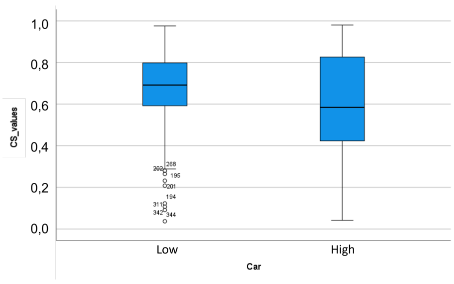


(b) Trips by bike

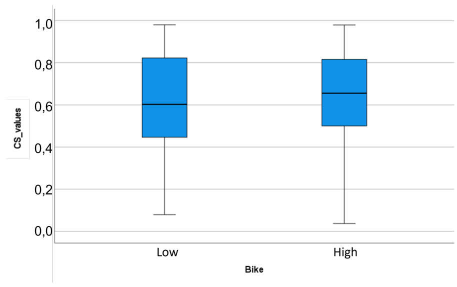


(c) Trips by foot

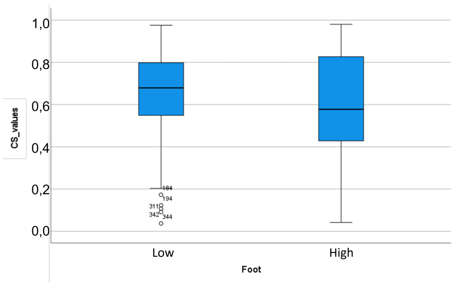
Figure 38: The relation between transport mode usage and CS-values based on non-western households



(a) Trips by car

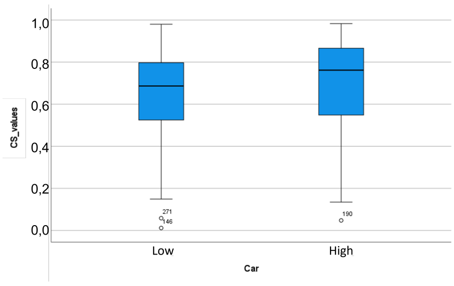


(b) Trips by bike

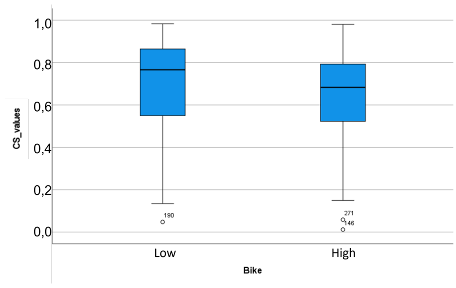


(c) Trips by foot

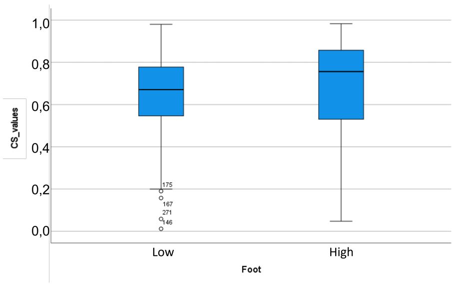
Figure 39: The relation between transport mode usage and CS-values based on households with benefits below state pension age



(a) Trips by car



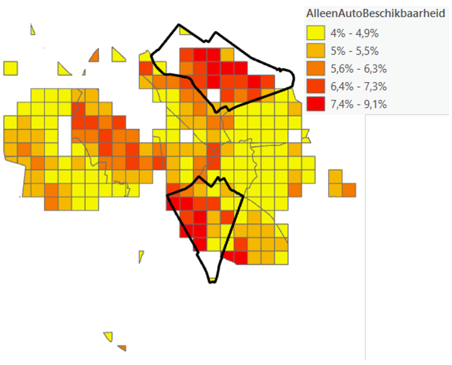
(b) Trips by bike



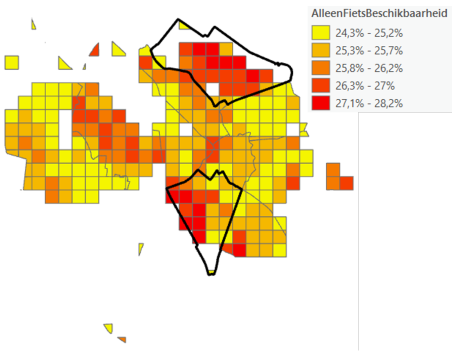
(c) Trips by foot

Figure 40: The relation between transport mode usage and CS-values based on one-parent households

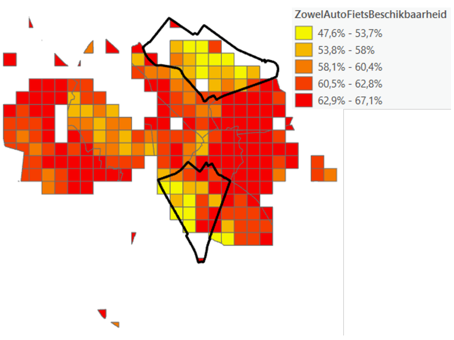
F Vehicle ownership in Overvecht and Kanaleneiland



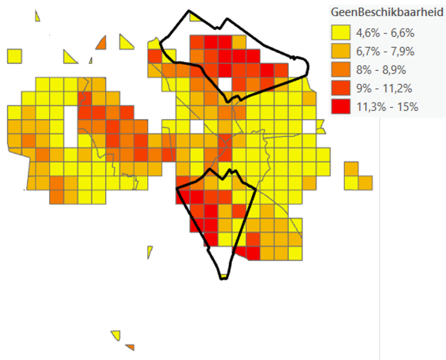
(a) Only car availability



(b) Only bicycle availability

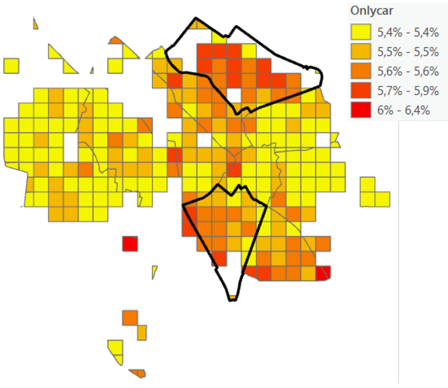


(c) Both car and bicycle availability

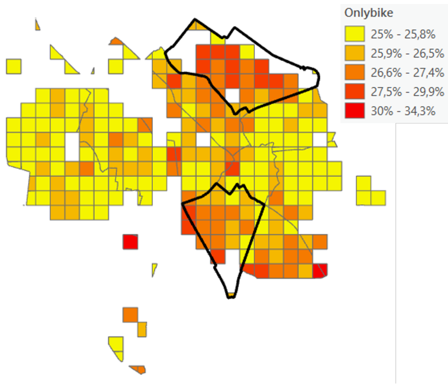


(d) Availability only by foot

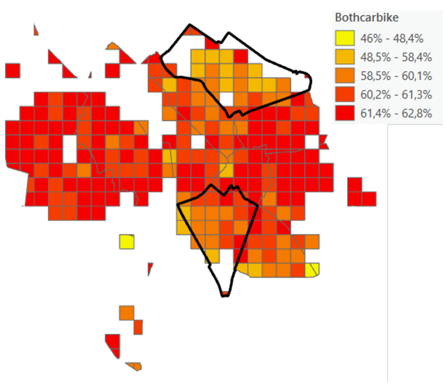
Figure 41: Vehicle ownership based on non-western background



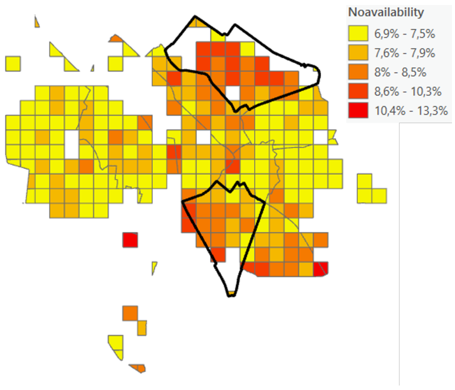
(a) Only car availability



(b) Only bicycle availability

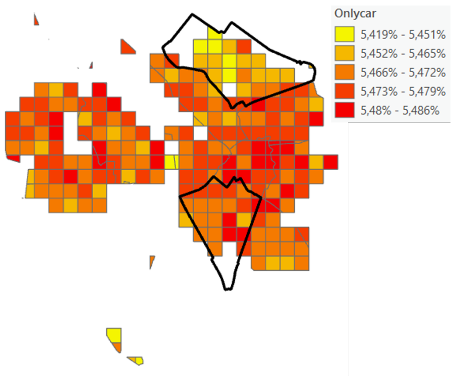


(c) Both car and bicycle availability

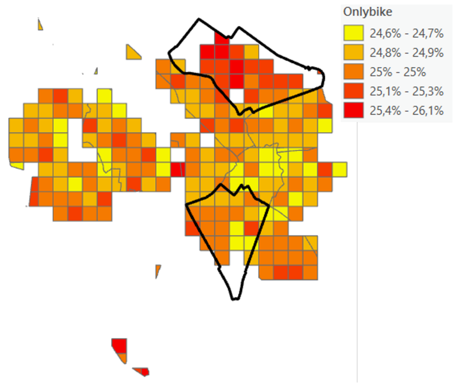


(d) Availability only by foot

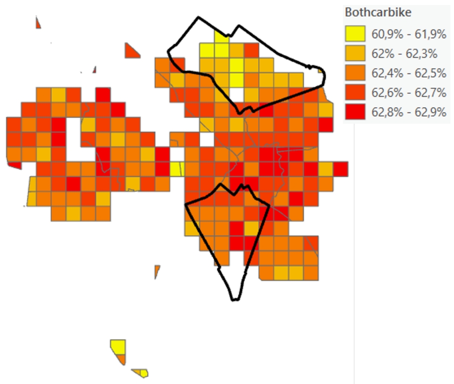
Figure 42: Vehicle ownership based on benefits below state pension age



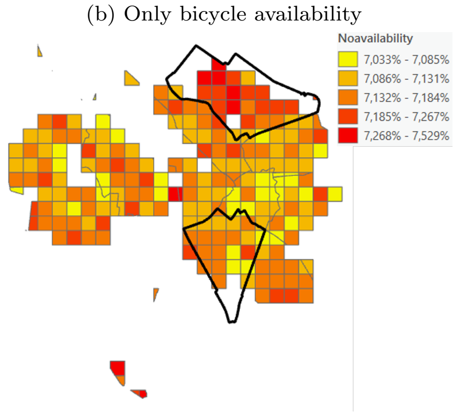
(a) Only car availability



(b) Only bicycle availability



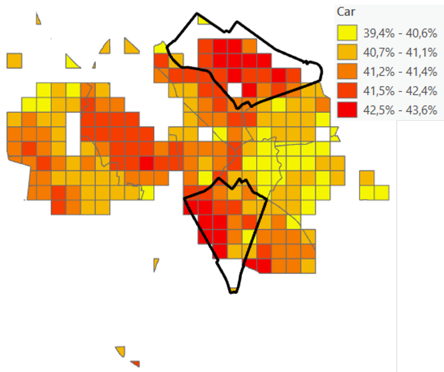
(c) Both car and bicycle availability



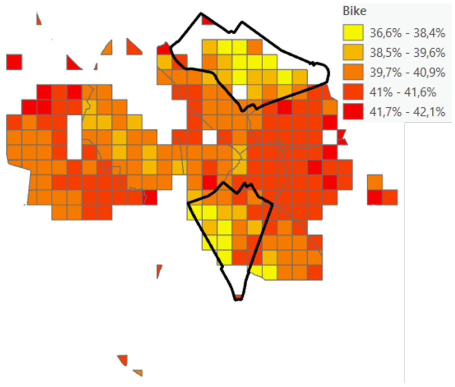
(d) Availability only by foot

Figure 43: Vehicle ownership based on one-parent households

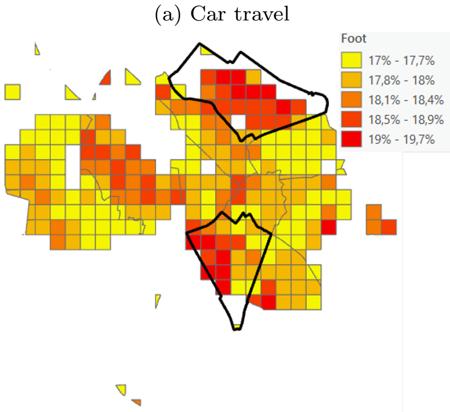
G Transport mode usage in Overvecht and Kanaleneiland



(a) Car travel

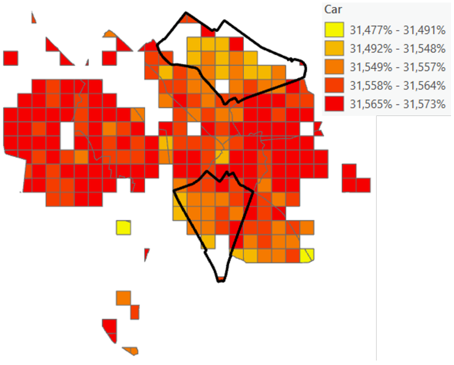


(b) Bike travel

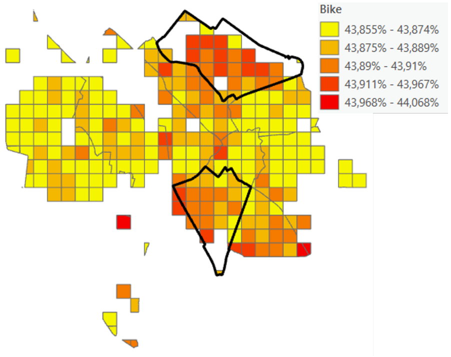


(c) Foot travel

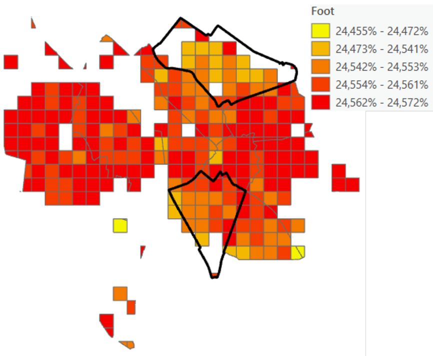
Figure 44: Transport mode usage based on non-western background



(a) Car travel

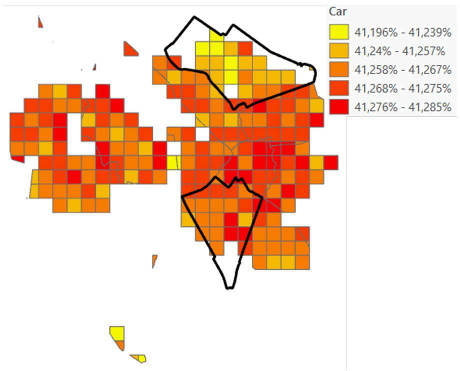


(b) Bike travel

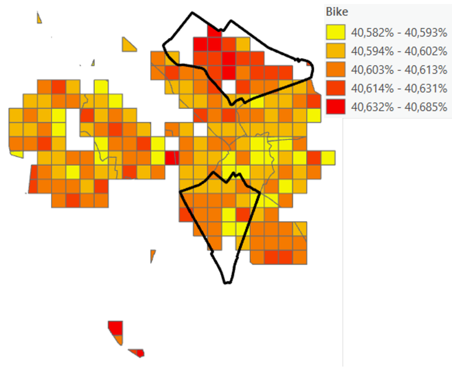


(c) Foot travel

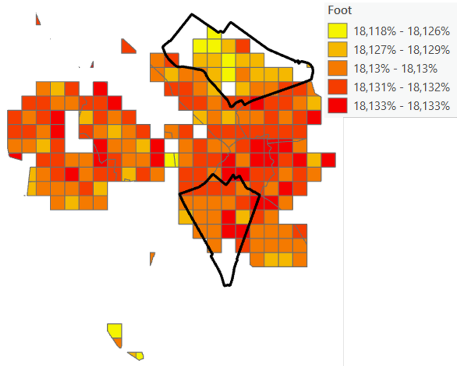
Figure 45: Transport mode usage based on benefits below state pension age



(a) Car travel



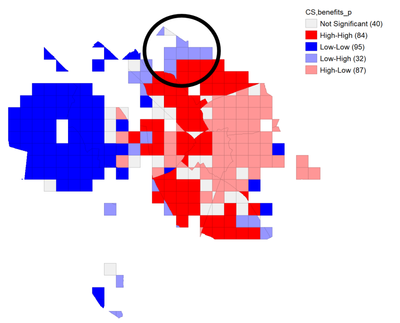
(b) Bike travel



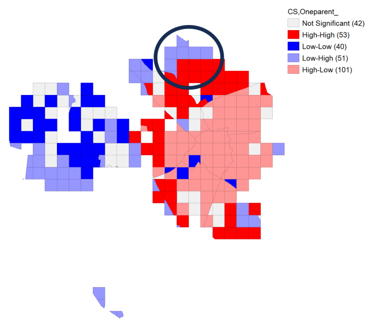
(c) Foot travel

Figure 46: Transport mode usage based on one-parent households

H Individual aspects with a negative influence on the 10-minute accessibility in Overvecht and Kanaleneiland with modal availability as factor



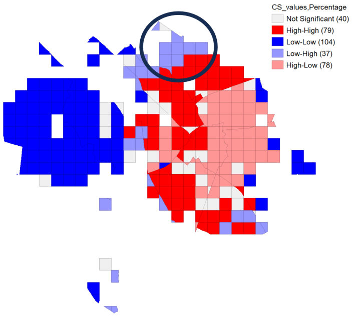
(a) People with benefits below state pension age



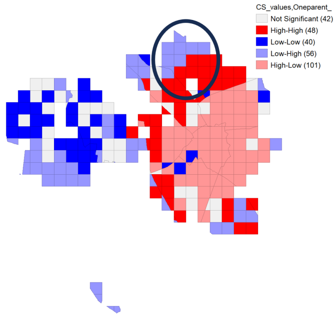
(b) One-parent families

Figure 47: The clusters between accessibility weighed by modal availability and socioeconomic characteristics

I Individual aspects with a negative influence on the 10-minute accessibility in Overvecht and Kanaleneiland with modal split as factor



(a) People with benefits below state pension age



(b) One-parent families

Figure 48: The clusters between accessibility weighed by modal split and socioeconomic characteristics

J Areas in the northwest of Overvecht and the west of Kanaleneiland

(a) Areas with low CS-values and low income in Overvecht

(b) Areas with low CS-values and low income in Kanaleneiland

Figure 49: Areas with low CS-values and low income