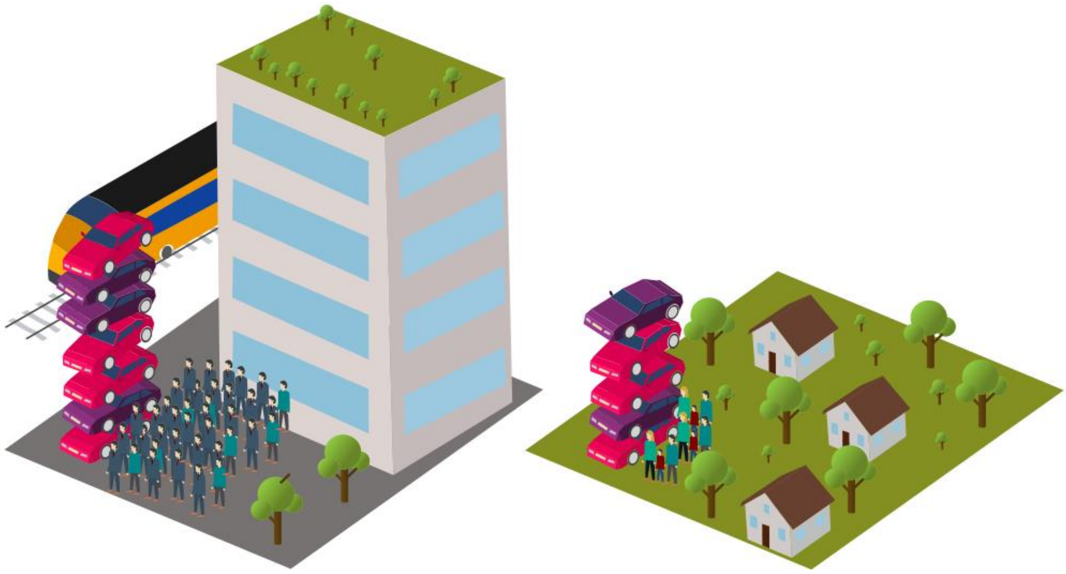

EXPLANATION OF HOUSEHOLD CAR OWNERSHIP WITH PROXIMITY TO TRAIN STATIONS

Quantification of household car ownership with proximity to train stations and a determination where parking standards in urban areas can be improved in the Netherlands

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19 September 2019

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Preface

Currently, in front of you is the thesis titled: "Explanation of household car ownership with proximity to train stations". This thesis is my final product of the study programme Civil Engineering and Management at the University of Twente in Enschede.

The past months of working on this thesis have been a challenging and inspiring experience. I want to thank Marie-José and Aukje van de Reijt from Goudappel Coffeng to allow me to work on this project. I have enjoyed working in the office, and therefore I would like to thank all colleagues and interns of the department Onderzoek & Gedrag. Mariska van Essen has been my daily supervisor at the office and has been of great help in the research methods and decision making. On top of that, I would like to thank the other colleagues of the Goudappel Coffeng and DAT Mobility that have been supporting me in gathering the data.

Furthermore, I would like to thank Bas Tutert, Hillie Talens and Frank Aalbers for sharing their expert knowledge about the practice of the current and past parking policy. At KiM, I would like to thank Mathijs de Haas for his rapid help with enriching the MPN database.

Next, I would also like to thank Tom Thomas and Karst Geurs from the University of Twente for their guidance of my research proposal and thesis. After our meetings, I always went home with an enormous list of new tasks but with an even longer list of new insights, which have helped me improving my work and keeping motivated.

Last but not least, I would like to thank my family and friends by supporting me (especially during the finishing of the last "open ends").

I hope you will enjoy your reading.

Dieuwert Blomjous

Deventer, 19 September 2019

Korte samenvatting (short Dutch summary)

Voor het parkeerbeleid voor nieuwe woningen in de Nederlandse stedelijke gebieden is de vraag ontstaan in hoeverre treinstations het autobezit van huishoudens beïnvloeden. Hoge bouwkosten in een beperkte ruimte met een hoog aantal benodigde parkeerplaatsen zorgen voor vertraagde of zelfs afgestelde bouwprojecten. Tegelijkertijd is de tendens onder jongvolwassenen om minder vaak of pas later een auto aan te schaffen. Daarom focust dit onderzoek zich op de invloedsfactoren van autobezit om de invloed van de nabijheid van treinstations te kwantificeren en deze bevindingen te gebruiken voor de verbetering van parkeernormen.

De relatie van de nabijheid van treinstations met autobezit van huishoudens is uitgebreid onderzocht door academici. De focus lag echter bij het effect van de afstand tot een treinstation en niet zo zeer bij de eigenschappen van het treinstation. Terwijl eigenschappen in onderzoek naar het verwachte aantal gebruikers van treinstation wel een rol spelen. Daarom is in deze studie onderscheid gemaakt in vijf type treinstations die verschillen in het dagelijks aantal passagiers. Het kleinste type station heeft minder dan 1000 dagelijkse passagiers en het grootste type station meer dan 75000. Van groot naar klein zijn de namen van de stationsklassen: Kathedraal, Mega, Plus, Basis en Halte. Het autobezit per huishouden is vergeleken op buurt niveau (CBS buurten) en hieruit bleek dat het grootste type treinstation een negatief (reducerend) effect heeft op het gemiddelde autobezit per huishouden in de buurt, terwijl het kleinste type nauwelijks tot geen effect heeft of het treinstation. Zelfs wanneer de effecten van andere variabelen als parkeervergunning, leeftijd en inkomen worden meegenomen in een meervoudig lineaire regressie model blijkt dat de grootste treinstations het grootste negatieve effect blijven hebben op het gemiddelde autobezit van huishoudens.

Uit deze resultaten volgt dat het gemiddelde autobezit per huishouden lager is bij een groter treinstation, hieruit volgt echter niet dat er een causaal verband is. Daarom is de verandering in gemiddelde autobezit per huishouden geanalyseerd voor en na de opening van nieuwe treinstations in Nederland. Deze nieuwe treinstations hadden echter geen significant effect op de verandering van het gemiddelde autobezit per huishouden. Dit kan verklaard worden door het kleine aantal buurten die nabij de nieuwe treinstations gelegen waren en de nieuwe treinstations waren de typen Basis en Halte die ieder nauwelijks tot geen effect hebben op het gemiddelde autobezit per huishouden. Uit deze studie blijkt dus niet of er een causaal verband is tussen treinstations en autobezit

Vervolgens zijn met paneldata van Mobiliteits Panel Nederland (MPN) de voorkeuren van de respondenten vergeleken met autobezit van het huishouden en zijn veranderingen in autobezit bij verhuizingen vergeleken. Uit het eerste gedeelte van de studie bleek dat zowel de voorkeur om te wonen bij een treinstation als daadwerkelijk te wonen in een gebied nabij een groot treinstation invloed heeft op het autobezit van huishoudens. Daarnaast bleek dat bij verhuizingen naar buurten met kleinere typen treinstations het autobezit van de huishoudens toenam. Ondanks de kleine steekproeven geven de studies wel de indicatie dat er zowel sprake is van effecten van de bebouwde omgeving (als treinstation) als zelfselectie.

Tot slot zijn de parkeernormen die gehanteerd worden door gemeenten vergeleken met daadwerkelijk autobezit in de buurten en met de kencijfers van CROW (deze kencijfers worden landelijk gebruikt ter indicatie voor parkeernormen). Voor twee huistypen (huur appartement en koop rijtjeshuizen) is geanalyseerd of er verschil zat in de accuraatheid van de parkeernormen. Het bleek dat over het algemeen gemeenten meer parkeerplaatsen vereisen voor nieuwbouw dan nu het daadwerkelijke autobezit is. Het minimum van de bandbreedte van de kencijfers van CROW

bleek toereikend voor gebieden nabij een Kathedraal of Mega, maar bleek te laag voor de kleinere typen stations. Uit deze studie volgt dat met name het beleid van gemeenten verbeterd zou kunnen worden door meer rekening te houden locatie specifieke factoren zoals de nabijheid van treinstations.

Extended abstract

In the Netherlands, parking standards are one of the factors that form a barrier to the development of housing. High building costs, in combination with the number of required parking places, result in less housing development than required or planned (REBEL, 2016). Although public transport is one of the explaining factors of a mismatch of parking standards and car ownership; there still lacks a quantification of the effect of proximity to train stations on car ownership in the Netherlands. Therefore, this study aims to quantify the influence of train stations on household car ownership to develop recommendations to improve parking standards in urbanised residential areas in the Netherlands. So, the main research question is the following:

Research Question	*What is the influence of proximity to train stations on household car ownership, and how can this relationship be used to improve parking standards in urbanised residential areas in the Netherlands?*

A literature study summarised the influencing factors of household car ownership. Several factors of the built-environment, socio-demographics and attitudes were influencing factors of household car ownership. Nonetheless, international studies have varying results about the effects of the proximity to train stations. The largest extent of those studies did not include a distinction in the service levels of the train station, while holds that the larger the service level of the train station, the larger the number of passengers. Therefore, this study analyses the effects of the proximity to different train stations types on household car ownership and tries to find out whether there is a causal relation between train stations and household car ownership.

Municipalities mostly base their parking policy on the CROW key figures. Those key figures are tables with suggested parking standards with a bandwidth (a minimum and a maximum number) for a specific house type (like terraced houses or rent apartments) dependent on the urbanisation level of the municipality and the urban zone (city centre, shell, rest built-up area, rest). The presence of a train station is not one of the factors that determine the bandwidth, but in CROW's report is mentioned that train station train stations have none to a reducing effect on car ownership (CROW, 2018a). Recently, a study to the applied parking standards of municipalities concluded that the municipalities use too less differentiation in their parking standards and use therefore require more than 200% too many parking places in most of the cases for rent apartments (BPD, 2018). Therefore, the applied parking standards and the key figures are analysed to find out whether there is a mismatch between actual car ownership and parking standards.

Multiple methods were applied to investigate the influence of train stations on household car ownership while controlling for other influencing factors. At first, a cross-sectional country-wide analysis is performed to quantify average household car ownership while controlling for the influencing factors of the built environment and the socio-demographics. National data aggregated neighbourhood level data (CBS Buurten) was the basis for this analysis. To overcome the limitations of a cross-sectional study, the neighbourhoods are analysed over time to find out more about causal relations of the influencing factors on car ownership.

Since the aggregated dataset does not contain household (mobility) preferences and travel behaviour, another dataset is used to overcome these limitations. Data from the Netherlands Mobility Panel (MPN) are used to find out whether either or both the built environment and travel preferences influence household car ownership. An advantage of this dataset is that this dataset is disaggregated: now it possible to analyse car ownership on a household level. This same dataset

was used to again get more insight into the causal relations of train stations on household car ownership. The different datasets are summarised in Table 0-1. Finally, case studies for different house types were performed to analyse parking standards, key figures in comparison to household car ownership.

Table 0-1 Framework of methods and datasets

	Aggregated	Disaggregated
One year	CBS Buurt data for 2016	MPN data for 2014
Multiple years	CBS Buurt data for 2005 - 2018	MPN data for 2013-2016

In the first part of the study was average household car ownership of the neighbourhoods analysed. This cross-sectional aggregated study showed that there was a significant effect of train stations on average household car ownership. Not only the distance to train stations were a subject of the study but different types of train stations too. Those types are defined by the number of daily passengers, the smallest train station type is called Stop (< 1000 daily passengers) and largest train station type Cathedral (> 75000 daily passengers) (Prorail, 2019). These categories are the most straightforward classification of train stations since the daily passengers are a result of the service level of the train stations. The effects of the train stations are visualised in Figure 0-1 and Figure 0-2.

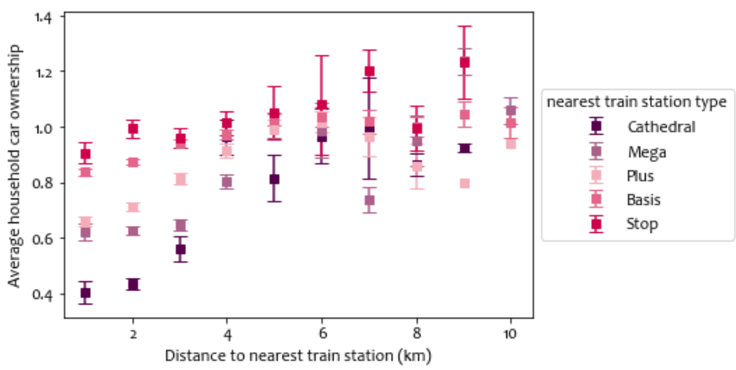


Figure 0-1 Average household car ownership for the aggregated distance to nearest train station per type and standard error

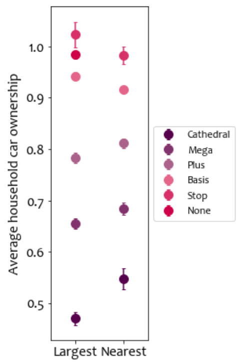


Figure 0-2 Average household car ownership per train station type for the two variables: largest train station type within 3km and nearest train station type

A Multiple Linear Regression model at the urbanised areas in the Netherlands was performed with the dependent variable average household car ownership. As in line with the existing literature, the distance to the nearest train station had a marginally positive effect on household car ownership. Nonetheless, even with controlling for other influencing factors as parking permits and socio-demographics, the type of train stations did a reducing effect on average household car ownership. Neighbourhoods with a Cathedral in a bike distance of at maximum three kilometres did have the largest negative effect on household car ownership, while there was no significant difference in household car ownership between areas with no or a Stop train station in that distance threshold.

Nevertheless, in the semi-cross sectional Multiple Linear Regression new train stations did not influence changes in average household car ownership model, in contrast to the hypotheses. In this analysis of changes between 2005 and 2015 were 41 new Basis and Stop train stations been built and the number of neighbourhoods with changes in the largest train station types was limited. From that place could be concluded there was no significant causal influence of the smallest train station types.

The first part of the disaggregated study focussed on the self-selection of households into train-rich or train-poor areas. Train-rich areas are areas with Cathedral, Mega or Plus stations within a bike distance (3km) and Train-poor areas have not any or a Stop train station within walking distances. The households in train-rich areas with the preference to live within bike or walking proximity of a train station (train-rich consonant households) had lower car ownership than households in train-rich areas that did not have the preference to live in those areas (train rich consonant households). On top of that, was no significant difference between households that live in train-poor areas with the preference to live in walking proximity of a train station. From there, could be concluded that both built environment as well as preferences of the residents have a significant effect on household car ownership.

The second part of the disaggregated study analysed changes in household car ownership of relocators. Nonetheless, the sample was too small for statistical significance. However, especially the results of relocators to areas with smaller train station types in proximity indicated the negative influence on household car ownership. The number of households with zero cars has decreased in the years before and after the move, while the number of households with one car has increased over time. Whereas, only a few households disposed of their car after the move. These results indicate a negative influence of the larger train station types. Nonetheless, more data about movers are required to gain significant results.

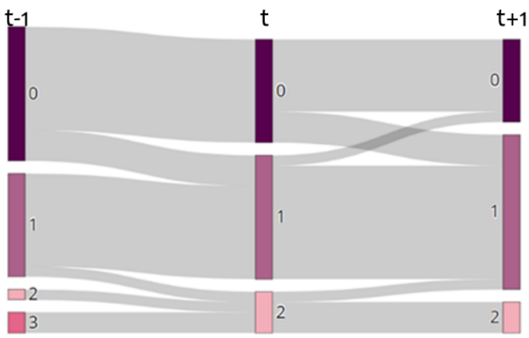


Figure 0-3 Changes in household car ownership with relocations at time step t, and t-1: one year before the move and t+1: one year after the move (n=26)

Finally, a brief analysis of the residential parking policies of the municipality showed that there were large variations in the parking standards among the municipalities. Although the structures were similar, especially the definition of urban zones and differentiation of parking standards among house types differed. From the case studies followed that for the neighbourhoods with different largest train station types in proximity holds, that in general, the parking policy of municipalities is an overestimation of household car ownership. Only, for rent apartments with a Cathedral or Mega train station in proximity are the parking standards a good indicator. This could be explained by the recent renewals of, for example, the municipality of Amsterdam to require a minimum of zero parking places per household of rental apartments. For the largest train station types followed that the minimum of the bandwidth of CROW's key figures spot on, but for the larger train station types were the minima too low. These results are visualised in Table 0-2.

The general recommendations for municipalities to improve their parking standards is to use more differentiation in parking standards. Not only by adding different house types but by better considering the local characteristics that explain household car ownership. From the case studies followed that the correctness of the advisory key figures differs per train station type in the proximity of the neighbourhood. Therefore, it is recommended to develop more advanced methods in the determination of parking standards. So, the required number of parking places fit the policy of the municipality.

Table 0-2 Overview of residuals of parking standards, CROW key figures and the MLR model in comparison to average household car ownership

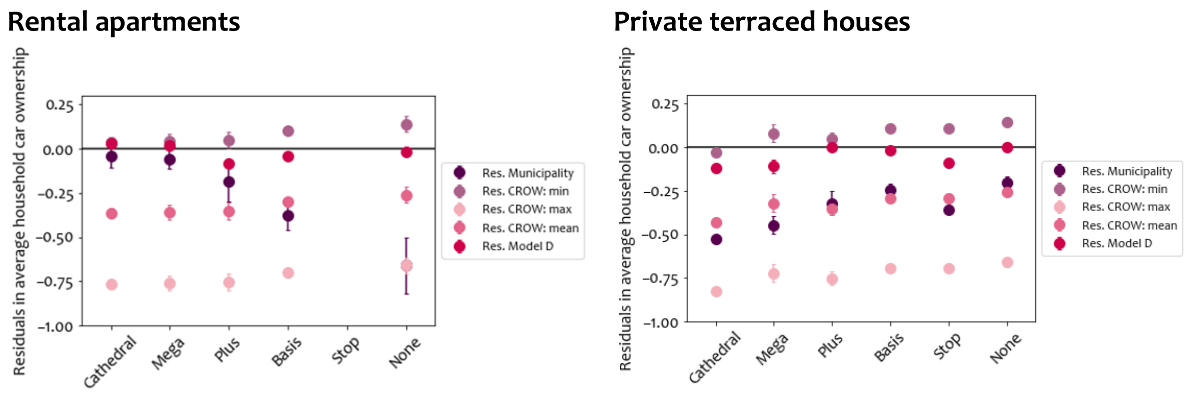


Table of Contents

1 Introduction

This section introduces the study and describes the chapters of the report briefly.

1.1 Problem Statement

In the Netherlands, parking standards are one of the factors that form a barrier to the development of housing. High building costs in combination with the number of required parking places result in less housing development than required or planned (REBEL, 2016). In the meantime, alternative transport modes as public transport or bikes are getting more attention to sustainable transport. Therefore, the question arises whether the required amount of parking places is really necessary for the inner city when alternative transport modes are available.

Currently, the space for residential parking is limited, mainly due to the "sky-high" housing shortage in the Netherlands (Capital Value, 2019). The shortage is the largest in the metropolitan municipalities and the lowest in the shrinking areas. Next to factors as slow licencing of building projects, shortage of builders and building materials, is the shortage of building locations appointed as a factor that delays construction of new buildings (Capital Value, 2019). The pressure of the housing market on public space and a trend of lower car ownership among young adults led in Amsterdam to a stop of offering public residential parking places in the inner city: new buildings may have a maximum of one parking place on the private area (Bakker, 2017).

In the municipality Utrecht and province Zuid-Holland are examples of the influence of the strict or high parking policy. In Utrecht, the parking standards led to housing development of smaller residences than needed for social rent. Smaller houses required less parking places; that way, the house development prices could be kept low (Municipality Utrecht, 2018). Next to that, in Zuid-Holland there were multiple examples of housing projects that were delayed or did not start at all, because of the parking assignment. On top of that, there were multiple examples of underutilised parking garages in the province of Zuid-Holland (Provincie Zuid-Holland, 2017). The latter were all close to high-level public transport (Provincie Zuid-Holland, 2017). Those examples show that the parking standards influence housing development. Therefore, it is important to know whether the required parking places fit actual car ownership.

Besides the examples, there is a general critic on municipalities' parking policy. BPD states that parking standards of the G4[1] and G32[2] do not match actual car ownership (BPD, 2018). Particularly, smaller rent apartments in the inner urban areas have the largest mismatch; a majority of the municipalities had standards of minimal 200% of the actual car ownership. The majority of municipalities works with the national averages (CROW's Key figures) for minimum parking standards, instead of local or project-specific factors influencing car ownership (BPD, 2018). In that way, they work with too less differentiation in parking standards.

Although public transport is one of the probable explaining factors of a mismatch of parking standards with car ownership; there still lacks a quantification of the effect of public transport on car-ownership. Therefore, it is essential that the influencing factors of actual car ownership in the Netherlands are analysed. Especially, the influence of train stations is an important point of interest. This study will aim to quantify the influence of trains stations on car ownership (while considering other influencing factors of car ownership) to develop guidelines to improve parking

1 Four large cities in the Netherlands with more than 250.000 inhabitants (The Hague, Utrecht, Amsterdam and Rotterdam) (CBS, 2018a)

2 Network of more than 32 municipalities excluding G4, in 2018 G32 changed into G40

standards. So, the result of this study will provide more insight into the required parking places when public transport is available.

1.2 Reading Guide

The first chapters were the summaries in Dutch and English, and after the table of contents, a brief problem statement is presented. The next chapter includes the relevant literature background, a conceptual model and the hypotheses. The research questions and scope of Chapter 3 are followed by a short description of the methodology in Chapter 4. The next four chapters are the results chapters with each a different method of the study and different research questions. The first of them, Chapter 5 contains a cross-sectional analysis of household car ownership. The next chapter contains an aggregated study to changes over time in household car ownership. Chapter 7 is about the disaggregated analysis of dissonant and consonant households and about changes in household car ownership by relations. The final result chapter (Chapter 8) goes deeper into the parking policy with two case studies. The chapters discussion, conclusion & recommendations and the appendices close the report.

2 Theoretical Framework

The first section of this chapter is an overview of car ownership in the Netherlands, and this section shortly describes the Dutch trends. The next three chapters respectively describe studies to influencing factors of car ownership, parking standards in the Netherlands and residential self-selection and life events. Finally, this chapter presents the conceptual models and hypotheses based on the literature study.

2.1 Car ownership in the Netherlands

At the start of 2018, there were almost 8.4 million passenger cars in the Netherlands (CBS, 2018c). From 2000, the number of passenger cars has been steadily increasing with on average more than 0.1 million cars a year, see Figure 2-1.

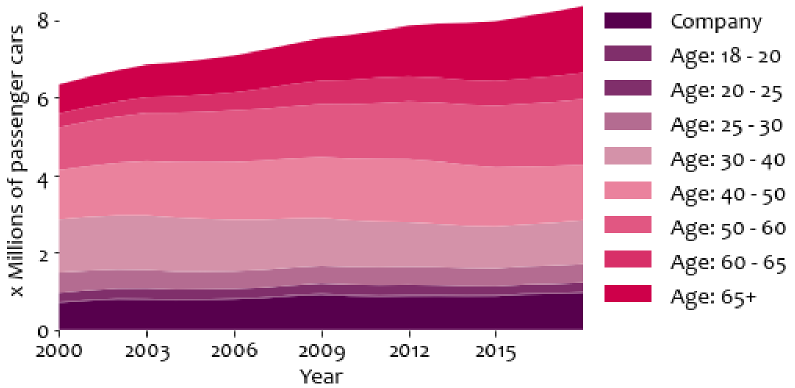


Figure 2-1 Car ownership in the Netherlands from 2000 to 2018 for different age groups. Data by (CBS, 2018c), processed by author.

Over the years, there is a growing interest in car ownership among young Dutch adults. Although the number of cars for the age group 18-20 is not visible in Figure 2-1, among the age groups 20-25 and 25-30 there is a slight decrease of the number of passenger cars over the years observable. Dutch research found out that this decrease is influenced by the level of urbanisation and the household size (Oakil *et al.*, 2016). Dutch young adults prefer living in high dense areas instead of rural areas, which results in less car ownership. The trend in delayed or voluntary childlessness results in less car ownership too: young families have higher car ownership and are more likely to move to the suburbs. Nonetheless, it is not known if this decrease is just a result of postponing car ownership or a persistent trend (Oakil et al., 2016).

Another observable trend is the increase of car ownership among older adults. This trend may be a result of the demographic ageing: in ten years, the population with age greater than 65 years has increased with a third (CBS, 2017b). On top of the demographic ageing, car ownership among over-65-year-olds has become more common than before. The conditions for the group 65+ are improved: they have become more wealthy, healthy and independent living than before (CBS, 2017a). Those conditions have a positive influence on car ownership.

So, although car ownership among younger adults is decreasing, in total car ownership is increasing in the Netherlands. Probably the increase of over-65-year-olds and their grown average car ownership are important causes.

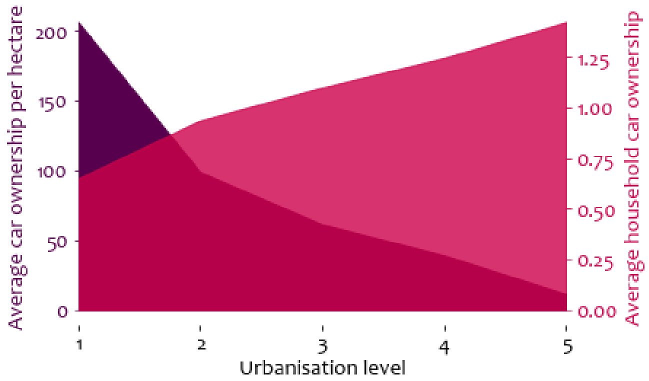


Figure 2-2 Average car ownership per hectare (purple) and per household (pink) in the Netherlands per urbanisation level of the neighbourhood. Data by (CBS, 2018b), processed by author.

A Dutch household owns on average about 1.1 cars (CBS, 2018b). Figure 2-2 shows that this average household car ownership is lower in the higher urbanised areas. But on the other hand, the average car ownership per hectare is higher. Average car ownership per hectare is strongly dependent on the density of the residents, see Figure 2-3 and Figure 2-4. In not urbanised areas (level 5) there are low densities; the residences are spread over a large area. Due to the high density in strongly urbanised areas (level 1), average car ownership per hectare is higher. Extremely urbanised areas differ by extremely high car ownership per hectare and extremely low car ownership per household in comparison to the other urbanisation levels.

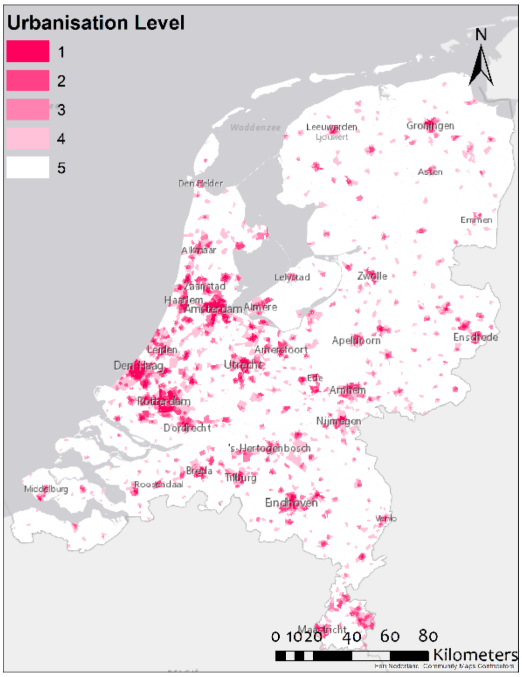


Figure 2-3 Urbanization level of "buurten". Data by (CBS, 2016a), processed by author.

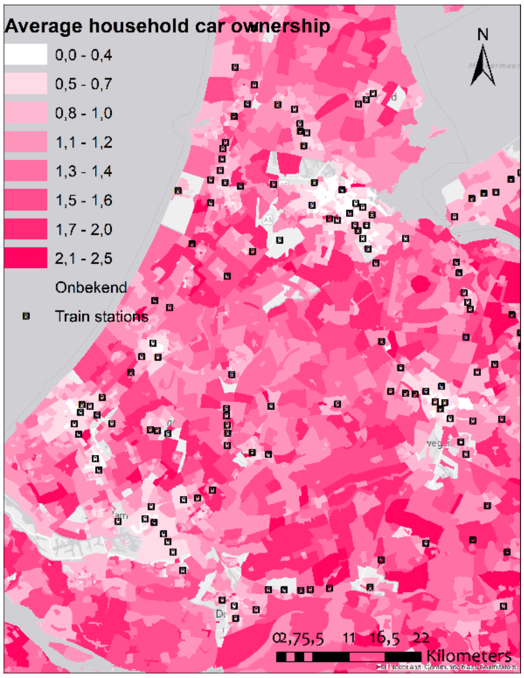


Figure 2-4 Average household car ownership in Randstad. Data by (CBS, 2016a), processed by author.

2.2 Influencing factors of car ownership

This section contains an overview of the existing literature about influencing factors of car ownership. The influencing factors of the built environment, socio-demographics and purpose & attitudes are discussed in the next sections. Finally, in an overview of the influencing factors the influence of the factors is compared to appoint the most influencing factors according to literature.

2.2.1 Built environment

The section built environment is categorized by the six D's: density, diversity in land use, design of the neighbourhood, destination accessibility, distance to transit and demand management (Ewing & Cervero, 2010). Only destination accessibility and distance to transit are combined with preserving doublings.

2.2.1.1 Density

A renown international overview shows that car dependence is strongly correlated with land use; cities across the globe with a high urban density are associated with low car ownership (Kenworthy & Laube, 1999). This relation is confirmed in later studies too, for example (Acker & Witlox, 2010), (Berri, 2009), (Hess & Ong, 2002), (Næss, 2009), (Potoglou & Kanaroglou, 2008) and (Zegras, 2010). Nonetheless, it became clear that density itself may not be the important factor that causes lower car ownership: the density represents or is correlated with the actual influencing factors. So explains Næss (2009) that in more dense areas residents are exposed to more congestion, noise and air pollution. They may have more awareness about the environmental impact of car traffic and they may have access to a higher quality of alternatives for transport modes (Næss, 2009). Kockelman (1997) concluded the same but included the association of high density with higher parking costs and limited parking places too. On top of that: density represents better walking connectivity, public transport accessibility and other factors (Ewing & Cervero, 2010). So, in the past, most researchers agree on the negative correlation of density with car ownership, but later on this effect is attributed to other influencing factors as accessibility, diversity and design.

2.2.1.2 Diversity in land use

In addition, a higher variety of land use is associated with lower car ownership (Potoglou & Susilo, 2008). This diversity is seen as an indicator for walkable areas; so the higher the diversity, the higher the walkability, the lower car ownership (Ewing & Cervero, 2010). There are multiple types of variables that represent the diversity, roughly they can be divided into jobs-housing balance and the proportions of land use types.

The jobs-housing ratio represents the variation in activity and residential areas (Stead & Marshall, 2001) and the amount of jobs represents just the activity of the neighbourhood. (Kockelman, 1997). The entropy index quantifies on a scale from 0 to 1 the land use balance. The entropy index can be expanded to the mean entropy index, then there can be accounted for multizonal neighbourhoods (Kockelman, 1997). The entropy index negatively impacts car ownership of two or more vehicles (Potoglou & Kanaroglou, 2008). The dissimilarity index measures the degree of integration of land uses (Kockelman, 1997). So, the entropy index shows whether all the different land-use types are equally available in the area, the dissimilarity index shows how well the different land-use types are mixed.

The mean entropy index is based on the different land-use types in the neighbourhood, see Formula 2-1 (Kockelman, 1997). The land-use types could be: residential, commercial, public, offices, industrial and recreation (Kockelman, 1997).

$$Entropy\ index = \sum_j \frac{P_j \cdot \ln P_j}{\ln J} \quad \text{2-1}$$

With:

P= Proportion of land use type j in the area

J= number of land-use types

2.2.1.3 Design of neighbourhood

The design of a neighbourhood is another factor that has been studied by many researchers. In the nineties in the USA, the effect of neo-traditional design on car use and ownership became an important topic (Acker & Witlox, 2005). Many empirical kinds of research claim a negative effect of neo-traditional neighbourhood on car ownership in comparison to traditional design (Li & Zhao, 2017). The biggest difference between the two is that the neo-traditional design is a more spread car-oriented design, while traditional design is a more compact walking and transit-oriented design. (Acker & Witlox, 2010) creates an overview of the indicators of urban design: block size, sidewalk system, cul-de-sacs and limited parking capacity. (Næss, 2009) states the design of neighbourhoods is an important topic in America, but in European context the emphasis is more on accessibility and distances to for example the city centre.

The design of the neighbourhood is often represented by the walkability of the neighbourhood. A rough indicator for walkability in the city can be formulated by the number of intersections in a neighbourhood, so the more intersection the better the walkability. Nonetheless, there are more advanced approaches. The walkability can also be measured by the seven C's: *connected, convenient, comfortable, convivial, conspicuous, coexistence* and *commitment* with for each C multiple variables for multiple groups of people with different demographics *(Moura et al., 2017).*

2.2.1.4 Destination accessibility & Distance to transit

Accessibility for passenger transport is defined as "*the extent to which land-use and transport systems enable (groups of) individuals to reach activities or destinations by means of a (combination of) transport mode(s)*" (Karst T. Geurs & van Wee, 2004). In contrast to the previous influencing factors, accessibility already includes both built environment and transport by definition. There are many studies that claim an association of accessibility and car ownership, although there is a disagreement about the direction (Acker & Witlox, 2010). There is claimed that for each transport mode higher accessibility with the respective transport mode results in higher use of that mode. But on the other hand, locations with high car accessibility can also have high accessibility for other modes, resulting in less car use (Kockelman, 1997).

2.2.1.4.1 Accessibility

There are many measures of accessibility. For example the job accessibility by a transport mode, where Næss (2009) points out that the concentration of facilities is more important than the distance to one single facility. The proximity to railway stations (Acker & Witlox, 2010) and metro stations (Li & Zhao, 2017; Zegras, 2010) results in lower car ownership; however, this result is not always significant in other studies (Næss, 2009). Distance to city centre is used as an indicator for among other things accessibility by public transport (CROW, 2018b). Furthermore, a distance decay function can be used to measure the level of access from for example a residential location to jobs (Karst T. Geurs & van Wee, 2004).

Measures of accessibility that could be used are access costs, contour measures and potential accessibility. Distance decay functions, that are used in potential accessibility, result in better predictions of transit ridership and are therefore more favoured to calculate accessibility

(Gutiérrez *et al.*, 2011). The potential accessibility can be used to measure the number of opportunities of a specific zone to all the other zones and the willingness to travel to the opportunities. The willingness to travel is expressed in an impedance function. Formula 2-2 (K.T. Geurs *et al.*, 2016) shows how the potential accessibility can be calculated. The distance decay function can be estimated by a relatively large selection of functions: exponential, power, inverse-potential, log-normal, log-logistic and exponential square-root (K.T. Geurs et al., 2016).

$$A_i = \sum_{i=1} D_j \cdot f(t_{ij}) \tag{2-2}$$

With:

A = Accessibility (number of opportunities equivalent) at zone i

D = number of opportunities at zone j

$f(t_{ij})$ = distance decay function of travel time t from zone i to zone j

2.2.1.4.2 *Transit Orientated Development*

Another important subject in research to the influence of train stations is Transit Orientated Development (TOD). TOD is seen as the solution for sustainable development (Arrington & Cervero, 2008). There are many definitions of TOD, most of them combine mixed land use and development near transit services with the goal to increase transit use and decrease car use (TCRP, 2002). A comparison of seventeen TOD projects in the USA shows that TOD is negatively associated with car ownership (Arrington & Cervero, 2008). Contrary, development around rail stations will by definition not lead to lower car ownership and use. In the case of Transit Adjacent Development (TAD), the development is physically near transit but fails to profit from this proximity (Renne, 2009). Low density, low diversity, car-oriented design and limited active transport accessibility of TAD result is higher car ownership and use in comparison to TOD (Renne, 2009).

Although studies show that there is lower car ownership in station areas, they do not agree on the impact of transit. Several studies show that the built environment has a more important impact on car ownership in rail station areas than rail itself (J. Cao & Cao, 2013; Chatman, 2013). For example, density and older housing is negatively correlated with car ownership (Chatman, 2013). In such studies, mostly the impact of rail is assessed as the proximity to a railway station next to the other D's and socio-demographics (Huang *et al.*, 2016; Jiang *et al.*, 2017). The same holds for proximity to metro stations (Li & Zhao, 2017). For example, the influence of proximity to public transport was only associated with vehicle miles travelled and not to car ownership (Jiang et al., 2017). Nonetheless, there are also studies that do find a significant negative effect of proximity to transit on car ownership in the case of urban transit (Liu *et al.*, 2018) or metro (Zegras, 2010). In Los Angeles the highest level of transit service was significantly negatively associated with car ownership (Houston *et al.*, 2014).

2.2.1.4.3 *Train station area*

The studies to car ownership near train stations use rules of thumb for the size of the train station areas. Mostly the areas are defined by the distance people are willing to travel to the train station. This distance is, for example, half a mile in America (Houston et al., 2014) and in China this distance is called a 15-min walk China (Li & Zhao, 2017). In the Netherlands, people prefer walking to the train station from home when the distances are smaller than 1.5km; however there is a 20% decline of people using public transport that is living 500- 1000m than 0-500 (P. Rietveld, 2000). The acceptable bike distance is between 1 and 3 kilometres as the crow flies from home to the train station. On average the travellers cycle about 3.4 km to the train station (Jonkeren *et al.*, 2018).

Fixed distance thresholds will not fully present the tendency to use public transport depending on the distance (Gutiérrez et al., 2011). Therefore, it may not be correct to use strict thresholds for distance to train stations.

2.2.1.4.4 *Conclusion*

So, the studies have various results about the impact of train stations on car ownership. The impact of public transport seems strongly dependent on the quality and suitability of the built environment. In the study to the relation of the proximity of train stations with car ownership, there should be paid attention to the distance decay of train travellers. The impact of stations far from the residences may not be caused by the station itself, since there may be hardly any train travellers living in that area.

2.2.1.5 *Demand management*

The sixth D is called demand management but stands in general for the impact parking supply and cost (Ewing & Cervero, 2010). Unfortunately, research on residential parking is very limited (Weinberger, 2012). The impact of residential parking availability can be seen as a limiting factor for purchasing cars; when the number of (off-street) parking spaces is scarce, the probability of owning cars is lower (Guo, 2013; Weinberger, 2012; Yin *et al.*, 2018). In London, parking supply together with availability of public transport was positively associated with car ownership (Liebling, 2014). However, there was only an effect of restricting parking supply in the areas in the centre: the outer areas kept more car-dependent. In the case of New York City, people that are limited to on-street parking have on average lower car ownership than people that have an option for driveway or off-street parking (Guo, 2013). Probably, the ease and guarantee of parking are decisive for purchasing and using a car (Guo, 2013). To lower that ease, Knoflacher (2006) suggests that parking facilities should be as accessible as public transport; the distance to car parking places should be at least as large as the distance to the nearest public transport stop. Then, people can have a more fair choice between driving car or using public transport (Knoflacher, 2006). Nonetheless, many studies conclude that only measures that involve pricing for parking will have a significant effect on reducing car use and ownership (Christiansen *et al.*, 2017).

2.2.2 Socio-demographics

Demographic factors, also called the seventh D, have an important influence on car ownership as well. Socio-demographics are mostly control variables in the built environment and travel studies. The most important variable in those studies is income: in general car ownership is higher in when income increases (X. Cao *et al.*, 2007; Guo, 2013; Næss, 2009; Potoglou & Kanaroglou, 2008; Zegras, 2010). However a study in Paris showed that the influence of income interacted with the built environment: the effect of income was only a significant influencing factor for car-dependent (less urbanized) areas (Cornut, 2016).

The household composition is influencing car ownership too (X. Cao et al., 2007). Age and gender positively influence car-ownership, but both may be correlated with income (X. Cao et al., 2007). The number of (working) adult household members and young children is positively correlated as well as the number of drivers licences (X. Cao et al., 2007; Potoglou & Kanaroglou, 2008). In comparison to house owners, have house renters lower car ownership (Li & Zhao, 2017) and even the size of the house matters in car ownership (BPD, 2018). The latter may again be correlated with income. Dutch research found out that income, house size and household composition did have the largest relative effects on car ownership (Maltha *et al.*, 2017)

2.2.3 Purpose and attitudes

Car-oriented attitudes result in more car use and ownership (X. Cao et al., 2007). So, if people have more preference for a certain model, they are more likely to use that mode. In general, the studies do not agree on the importance of attitudes in comparison to built environment; many examples conclude built environment has a significant influence in spite of preferences, while other studies conclude that attitudes are more dominant (van de Coevering *et al.*, 2018). The socio-cultural background may influence travel preferences too. In a study to Dutch bicycle preferences were found that Catholic municipalities have a more car-oriented attitude, while the Protestant municipalities have a more bicycle-oriented attitude (Piet Rietveld & Daniel, 2004). In the Netherlands, this difference in socio-cultural background is traditionally the difference between respectively the South and the North.

An alternative view is that the preferences are inextricably bounded with the residential area (Næss, 2009). People living in car-dependent areas may develop positive attitudes to car, while people living in urban areas that do not need a car may develop negative attitudes. Simply because of their experience with (the effects of) cars (Næss, 2009). The causality can be the other way around too; people can also choose a residential location based on their travel preferences and needs. This effect is also called residential self-selection (X. Cao *et al.*, 2009). In San Francisco, people were self-selecting residential areas demo-graphically based (Bhat & Guo, 2007). For example low-income people chose high-density areas to reduce car costs, and this results in lower car ownership of those households, where for example households with senior adults had high preference for cars and thereby chose for lower density areas (Bhat & Guo, 2007).

2.2.4 Dutch development locations

New residents at new building sites have, on average higher car ownership and mobility than the average Dutchman (Snellen *et al.*, 2005). The effect of VINEX (a Dutch massive housing development policy to reduce non-necessary car movements) on car ownership and mobility has been studied. It turned out, development locations at inner-city locations resulted in lower car mobility of the residents than the average resident: the nearer the city centre, the lower the car ownership of the residents of the new building suites. This effect is less attributed to the locations itself (1%), than to the characteristics of the residents (6.5%) as education level, age, household composition etcetera (Snellen et al., 2005). Young highly educated families with children are more sensitive to the built environment than other residents. Nonetheless, when zooming into specific locations, supply of public transport is the greatest success factor in minimising car ownership (Snellen et al., 2005).

2.2.5 Overview

The previous sections briefly discussed the influencing factors of car ownership per subject with their influence on car ownership. Table 2-1 provides an overview of all the discussed variables. In the column Source is only referenced to one single source; however some of the factors have multiple sources. Table 2-1 only mentions the oldest studied source.

Studies have various results about the influencing factors. There is an agreement that the demographics have an important role in car ownership and that the built environment influences car ownership too. In demographics: income, age and household compositions are the most important factors. The effect of the built environment is mostly attributed to proximity to city centres and public transport. Nonetheless, the latter is mostly not directly measured but indirectly by density or distance to city centre. In other studies or reports there is expected that public transport influences car ownership, but no quantification of this effect was available.

Less studied subjects, parking availability and costs, are seen as even more important car ownership reducing factors. Nonetheless, there are not many studies about the European or even the Dutch practice.

Table 2-1 Overview of influencing factors of car ownership

Type	Variable	Source	Direction
Density	Density of residents	(Kenworthy & Laube, 1999)	-
Diversity	Entropy index	(Ewing & Cervero, 2010)	-
	Dissimilarity index	(Kockelman, 1997)	-
	Job- housing ratio	(Stead & Marshall, 2001)	-
	Job density	(Stead & Marshall, 2001)	-
Design	Walkability	*(Moura et al., 2017)*	-
	Year of built (residential buildings)	(Chatman, 2013)	+
Destination accessibility & Distance to transit	Proximity to train station	(Acker & Witlox, 2010)	+
	Density of stops	(Næss, 2009)	-
	Accessibility	(Kockelman, 1997)	-
	Distance to city centre	(Acker & Witlox, 2010)	+
	Level of service	(Houston et al., 2014)	-
Demand	Number of parking places	(Weinberger, 2012)	+
	On-street parking	(Guo, 2013)	-
	Parking costs	(Christiansen et al., 2017)	-
Socio-demographics	Income	(X. Cao et al., 2007)	+
	Household size	(X. Cao et al., 2007)	+
	Number of Workers	(X. Cao et al., 2007)	+
	Age of residents	(X. Cao et al., 2007)	+
	House composition	(Oakil et al., 2016)	+
	Ownership of house (private property)	(Li & Zhao, 2017)	+
	Education level	(Snellen et al., 2005)	-
Preference and attitude	Car oriented attitude	(X. Cao et al., 2007)	+

2.3 Residential self-selection and dissonance

In the recent literature about the built environment and travel behaviour is self-selection an important topic of interest. The discussion about the influence of self-selection is about the causality: are people travelling actively because of the spatial characteristics of their neighbourhood, or did they deliberately choose their residential location because of their travel preferences (X. Cao *et al.*, 2010)? There are several definitions; however, the following is used in this section: "*the tendency of people to choose locations based on their travel abilities, needs and preferences*" (Litman, 2018). Although, a better suitable definition for household car ownership would be: *the tendency of households to choose locations based on their travel abilities, needs and preferences*. The general question is: does the residential area influence attitudes or is the residential area selected by attitudes? Nonetheless, there are many conceptualizations that analyse the causality or among the factors in the triangle: attitudes, built environment and travel behaviour (X. Cao et al., 2009; Heinen *et al.*, 2018), where most of the papers focus on the causal relation of preferences with built environment (van de Coevering et al., 2018).

A Dutch case in The Hague has found only a little effect of travel preferences on location choice but found that people moving to train station areas used the train more if train use was the reason of location choice (Ettema & Nieuwenhuis, 2017). Nonetheless, this study was only performed at three TOD locations in The Hague. A recent Dutch study found out that both people changed their attitudes based on residential location and that dissonant people did change their residential location to a location matching their preferences (van de Coevering et al., 2018). The results showed that people with lower income didn't have a high probability in reducing their dissonance by moving to an area that meets their preferences. Nonetheless, to the knowledge of the author are no Dutch studies to residential self-selection and car ownership. However, car ownership is seen as a mediating variable for travel behaviour (Acker & Witlox, 2010); there is a strong relation between car ownership and car use. So, this indicates that there might be a bi-directional relation between built environment and preferences that effects car ownership in the Netherlands too.

Indeed, there are a few international studies regarding car ownership and self-selection. X. Cao et al. (2007) could not confirm the causal relationship between BE and car ownership; built environment and socio-demographics could better explain car ownership. A recent study in Norway showed that the distance to the city centre is positively correlated with car ownership and showed that moving towards the centre results in less car ownership and the other way around (X. Cao *et al.*, 2019). Next to the distance to city centre, job-housing balance and density had a negative association with car ownership; therefore high dense areas with high job density may reduce car ownership (X. Cao et al., 2019).

When households cannot self-select into desired areas or dwellings and live in a residence that doesn't correspond to their (travel) preferences, they are classified as dissonant (X. Cao et al., 2019; T. Schwanen & Mokhtarian, 2005). Consonant residents have moved to areas that meet their preferences. In worldwide studies, travel preferences have been the second-tier in location choice, which results in households living in areas that do not match the travel preferences (Wolday *et al.*, 2018). For example in Olso, dissonant residents in areas with transit in proximity have lower frequency of transit use than consonant residents (X. Cao et al., 2019). Most of the studies focus on the relation of residential dissonance and travel behaviour. Nonetheless, there are no articles found by the author of car ownership among dissonant and consonant residents in train station areas.

There are various methods for defining dissonant residents. They vary from binary static groups to more continuous scores or proportions of dissonance (Tim Schwanen & Mokhtarian, 2004). Important aspects are travel preferences, residential choices and life events and attitudes. A recent study to public transport areas defined a 3x3 matrix with transit-rich, average and poor zones and high, medium and low transit preference based on the scores for those variables (Wolday et al., 2018). Dissonant residents have no matching preference with their residential area, and consonant residents live in matching areas.

The main importance of this causality is the effect of investments in the built environment. When, for example, a new train station is built in a residential area, the effectiveness may be influenced by the attitudes of the residents. Therefore, investment in public transport in a rural area might not generate the same amount of users as in public transport accessible areas (van Wee, 2009). Residents in the rural area may have self-selected into low train accessible areas because of their preference for the car. In the case of a new train station, the current residents may not have train oriented preferences and therefore use the train less often than residents with the preference for train. Then, only new and dissonant residents are likely to use the train more frequently. In the case the built environment influences travel preferences, the current residents may develop train oriented attitudes and switch to use the train more often. So, in terms of the effectivity of policy measures it is important to get more answers about the causal relation of built environment and travel preferences.

2.4 Parking standards

Parking standards are the number of parking places that must be supplied at a specific location (Litman, 2006). In practice, the parking standards are used for new development or renovation building projects. This section describes the Dutch practice of the standards and describes academic studies to the parking standards.

2.4.1 History of parking policy in the Netherlands

The first parking policy in the Netherlands dates from the sixties; parking problems started to rise and led to a high number of parked cars in the public space. The general mental legacy was facilitating the car; the car had become very important. The municipalities could from now on start with paid parking. In the seventies the cars became more of hindrance in the public space. Therefore, minimum national parking standards were used for companies to guarantee enough parking places for the company and to have less parking interference for the neighbourhood (Coevering *et al.*, 2008). In 1977, the SVV (Structural action programme Traffic and Transport) was initiated and finally appointed at 1981 (Ministerie van Verkeer en Waterstaat, 1988). The demand for parking was not being followed anymore because a more directing policy tried to negatively influence the parking demand in the inner city (Coevering et al., 2008). The goal was to make the areas liveable and accessible again. Therefore, the municipalities were supposed to reach those goals with their more reluctant local policy.

In 1988, the parking policy shifted to strictly national policy: ABC-location policy together with minimum parking standards. In the Fourth Nota, the ABC- location policy matches companies with location types. A-locations were close to train stations and had low maximum parking standards, C-locations had good car accessibility and B-locations had both. Corresponding company types could locate at their location type. Although the goal was to increase the use of public transport, in reality the policy increased car use at the already more overloaded roads because most of the employment was created at B-locations (Hilbers & Snellen, 2009). On top of that, public transport services were not sufficient (Coevering et al., 2008), or built too late (Snellen et al., 2005).

In the same period, the ASVV was published: a guide for urban traffic facilities. This guide contained the first Key figures for parking and was published by the precursor of CROW (Studiecentrum Verkeerstechniek, 1986). Those Key figures represented the minimum number of parking places for different types of houses and could be used to determine the number of parking places to construct. Reduction factors were implemented for large and middle large cities and good public transport service at among other things the houses. The numbers and reduction factors were based on policies of the larger cities and reports (Studiecentrum Verkeerstechniek, 1986). Finally, from 2004 the national ABC-policy was not valid anymore: the provinces and municipalities became responsible for their parking policy to avoid parking nuisance (Coevering et al., 2008). The timeline of parking policy is summarised in Table 2-2 and the current situation is discussed in the next section.

Table 2-2 Overview of the time line of residential parking policy

'60	Demand following policy and first paid parking (Coevering et al., 2008)
'70	In 1977: Compulsory establishment of traffic and parking policies, plus compulsory approval of central government. The policy is officially appointed in 1981 (Coevering et al., 2008)
'80	No central government approval compulsory, municipalities itself are responsible for their local policy (Coevering et al., 2008)
'90	Compulsory National ABC location demand lowering policy & CROW Key figures published in ASVV in 1992 (CROW, 2004) (CROW, 2004)
2006	Again, no central government approval compulsory, municipalities itself are responsible for their local policy (Snellen et al., 2005)
2016	Compulsory parking standards in Zonal Plans instead of Building Regulations (IenW, 2019)
2018	Revision CROW Key figures (CROW, 2018b)

2.4.2 The current practice of parking standards in the Netherlands

In the Netherlands, the local authorities (the municipalities) determine the minimum parking standards (Mingardo *et al.*, 2015). Minimum standards make sure the specific location has enough parking capacit y to facilitate the demand. So, the visitors and residents of the new location are not disturbing their neighbourhood by parking in the area (Mingardo et al., 2015).

Before 2018, most of the municipalities controlled parking standards in the building regulations. However, in 2014 for the Housing Act has been decided to remove the Urban planning regulations: the parking standards needed

from 2018 to be regulated in the Zoning plans of the municipality (IenW, 2019). In practice, municipalities have made a new parking standards umbrella plan and dynamically referenced to the umbrella plan in Zoning plans. For the municipalities, this change was a possibility to thoroughly update the existing parking standards.

Key figures (Dutch: *kengetallen*) of CROW are often confused as the parking standards (CROW, 2018b). Nationwide CROW's Key figures are recognised as official guidelines, but do not have to be obeyed (IenW, 2019). Municipalities are allowed to deviate within a certain bandwidth from the national guidelines or set up 'reasonable' parking standards on their own (IenW, 2019). CROW applies bandwidths so that municipalities can customise the parking standards on local characteristics (CROW, 2018b). Those customisations are needed since the parking demand depends on the local characteristics of the specific situation (CROW, 2018b). The municipalities can only deviate from their parking standards if the function of the new development location is not described in their policy or there should be special circumstances.

Nonetheless, municipalities are criticised by their too less customised policy of parking standards. Many municipalities apply CROW's Key figures with too less differentiation among the specific locations (BPD, 2018). The standards may be one of the reasons why ambitious housing development projects stagnated (REBEL, 2016). The high building costs of parking places led to developers aborting the projects (Provincie Zuid-Holland, 2017). If a reduction in car ownership is expected, investing in residential parking may have high risks.

In international context Donald Shoup is an important criticaster of the minimum parking standards: local authorities do not take into account the costs of parking places and use the maximum observed parking demand as the minimum required parking supply (Manville & Shoup, 2005). The easiest way to get rid of the existing parking standards is a translation from minimum to maximum parking standards (Manville & Shoup, 2005). When using flexible or maximum parking standards, the residences can become more affordable and more money is available to create better access to sustainable mobility (Das & Jansen, 2016). The municipality Amsterdam is Dutch example of more progressive residential parking policy: maximum parking standards are applied in the inner city centre and locations near intercity train stations (BPD, 2018).

So, the role of parking standards is getting more and more attention by project developers, authorities and academics. Although customisations are advised, the Dutch practice is still an application of minimum parking standards based on national averages for most of the municipalities.

2.4.3 CROW's Key figures

Many of the municipalities base their parking standards on CROW's Key figures. The Key figures contain average car ownership per dwelling based on general characteristics (CROW, 2018b). Therefore, the numbers represent car ownership of the average residents of the Netherlands. So, the numbers do not represent the exact situations or are not that comprehensive that it is applicable for each case. For each type of housing, CROW presents tables with the minimum and maximum bandwidths. Table 2-3 contains an example of the Key figures for a specific house type.

Table 2-3 Copy of Dutch CROW's Key figures for one specific type of housing, in the Dutch language together with English translations (CROW, 2018b)

Koop, huis, vrijstaand *(= Private detached house)*								
	Parkeerkencijfers (per woning) *(=parking standards per dwelling)*							
	Centrum *(= centre)*		schil centrum *(=shell)*		rest bebouwde kom *(=Built-up area)*		Buitengebied *(=outside built-up area)*	
	min.	max.	min.	max.	min.	max.	min.	max.
zeer sterk stedelijk *(= Extremely urbanised)*	1.1	1.9	1.3	2.1	1.6	2.4	1.9	2.7
sterk stedelijk *(= Strongly urbanised)*	1.2	2	1.4	2.2	1.7	2.5	2	2.8
matig stedelijk *(= Moderately urbanised)*	1.4	2.2	1.5	2.3	1.8	2.6	2	2.8
weinig stedelijk *(= Little urbanised)*	1.4	2.2	1.7	2.5	1.9	2.7	2	2.8
niet stedelijk *(= Not urbanised)*	1.4	2.2	1.7	2.5	1.9	2.7	2	2.8
Opmerking *(=Remark)* Aandeel bezoekers: 0,3 pp per woning *(= share of visitors is 0.3 per dwelling)*								

In the CROW Key figures, high-grade public transport locations are not included in the tables. Nonetheless, high-end public transport locations are mentioned as influencing factor of the parking demand. The effect varies from none to the reducing effect, depended on the size of the city and the level of facilities of the neighbourhood. There is also mentioned that the share of the parking demand of visitors is lower: they are more likely to use Public Transport, and with parking regulation they are stimulated to not come by car.

2.4.4 Expert opinions about CROW's parking Key figures

This section consists of a combined summary of personal communications (pc) with parking and parking or Key figures experts. From the literature, study followed that many municipalities base their parking standards on the Key figures. Therefore, experts are interviewed to get more background of the Key figures and to find out how they should be implemented. The interviewees were Bas Tutert, Hillie Talens and Frank Aalbers.

2.4.4.1 *Start of CROW's parking Key figures*

Hillie Talens (project manager at CROW, managing the formation process of the Key figures) tells about the creation of the Key figures (pc, 2019). The first Key figures originated from 1986 and were published in the ASVV (Recommendations for traffic facilities in the built-up area), a semi-official guideline for traffic facilities. Since the sixties, it has become clear that parking should be regulated: the living areas were not built for parking places, and consequently squares and streets became oversaturated with cars. Later on, municipalities were forced to develop policies about (residential) parking regulations. The goal of CROW's Key figures was a tool for municipal traffic engineers to have a prompt indication of the required number of parking places for (new) development locations and to guide municipalities in developing parking standards. More information about the start of parking policy in the Netherlands can be found in the Theoretical Framework (Chapter 2.4.1).

2.4.4.2 *Development of the Key figures*

Frank Aalbers (Traffic Engineer at Goudappel Coffeng, adviser of development CROW parking Key figures) explains the development of the Key figures (pc, 2019). His role for the Key figures was coupling the number of expected traffic and the required number of parking places for non-residential locations. Over the years, the parking Key figures have been improved by the differentiation among urbanisation levels, urban areas and in the current version (2018) house types. Public transport has been a part of the ABC-location policy and in the early Key figures (see Chapter 2.4.1), but are in the current Key figures processed too. The zones: centre, shell, other built-up area and outside built-up area are not intended as their geographical names indicate. Therefore, Aalbers refers to the Key figures of 2004; the zones are based on the availability of public transport. For example in the centre, fewer people use the car because there are more alternative transport modes available. Therefore, the parking standards can be lower in this area than for example the shell of the city centre or even the rest of the built-up area with less available public transport (CROW, 2004). So, Aalbers emphasises that the alternative transport modes accessibility of the location is a more determining factor than the geographical location itself.

2.4.4.3 *Implementation*

Hillie Talens goes on to the implementation of the Key figures. They are based on literature research and practical experiences and should be therefore a good indication for the demand. However, the Key figures are predictions, and the numbers are not exact representations of the future residents' car ownership. Actual car ownership may be lower or higher.

Notwithstanding, before 2016, municipalities referred directly to the CROW Key figures as the municipal parking standards. In the *Model Bouwverordening (*Example Municipal Building Regulations) as a reference for the number of parking places to CROW Key figures as parking standards. Municipalities reproduced this reference in their Building Regulations, which should be obeyed by the project developers. The CROW Key figures were even used in the jurisdiction to reject or accept the proposed number of parking places of development. From 2016, the municipalities were forced to integrate the parking standards in the *bestemmingsplannen* (zoning plans). Therefore, the CROW Key figures are not directly used as parking standards anymore but are first democratically appointed.

Bas Tutert (currently Traffic and Transport policy servant at municipality Ede, was involved by the development of CROW's guidelines 2004) tells more about the implementation of the Key figures (pc, 2019). The tables of the guidelines are pragmatic; they provide insight into the effects of decisions. For example, for a specific house type is the difference between centre or shell directly visible. Nonetheless, Bas Tutert mentions that the Key figures are empirically based and are not exact numbers of the required number of parking places.

Aalbers warns about the implementation of the urbanisation levels. The urbanisation level is currently used as the urbanisation level of the municipality. For example, Almelo (level 2) has a higher level of urbanisation than a city as Emmen (level 4). Although Emmen even has more residents, the urbanisation level of the municipality Emmen is very low because it includes the periphery too. So, Aalbers argues whether the city centre of Emmen with a train station connection should be treated as a hardly urbanised area. On top of that he states that some municipalities don't want to take the risk that too less parking places are built: if too many parked cars are the direct surroundings leading to nuisance, the municipalities are (financially) responsible for solving the problem. Therefore, some municipalities are reluctant to applying low(er) parking standards. Finally, Aalbers warns for directly applying the Key figures tables on the locations in municipalities: municipalities should better take into account the local factors as public transport availability or other factors that are mentioned in CROW's guidelines parking Key figures. (pc, 2019)

2.4.4.4 Concluding

The three experts warn for directly applying the Key figures tables without taking into account the local characteristics. The tables are explicitly designed as a tool and not as the parking standard. The tables should not be used as an absolute minimum, but as an indication of future car ownership which may be (slightly) lower or higher in reality. By taking into account the local characteristics, there can be deviated from the Key figures, or there can even new parking standards be created.

2.5 Conceptual model

A conceptual model, with the literature study as the foundation, provides an overview of the influencing factors of household car ownership. Only the overarching headers of groups of variables are mentioned in this framework to remain an overview. The model is shown in Figure 2-5. The relations in this figure will form the basis of the research on the influence of train stations on household car ownership.

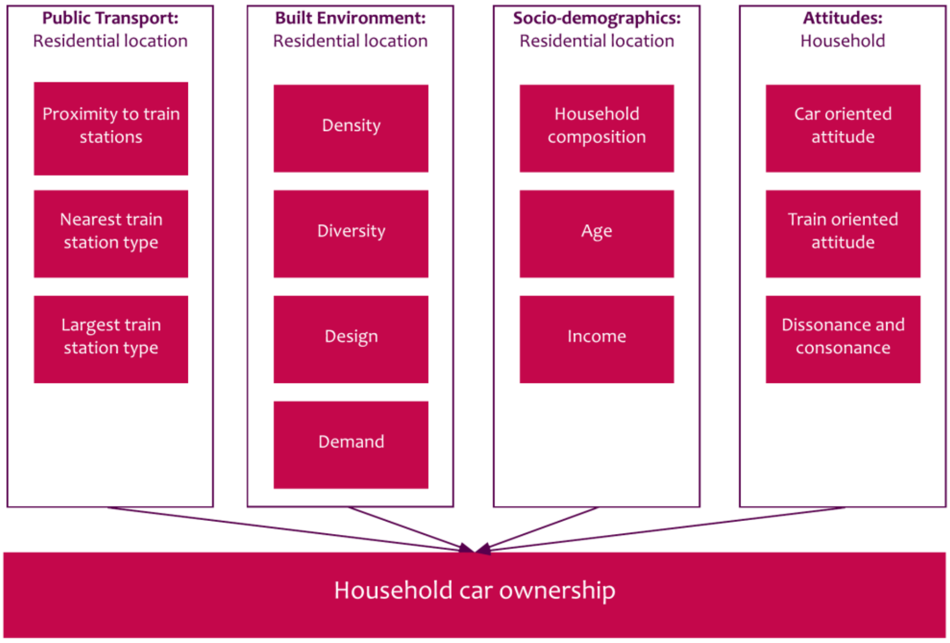


Figure 2-5 Conceptual model

2.6 Hypotheses

Based on the literature review and conceptual model, the following hypotheses are established that fit the problem:

1. The longer the distance to a train station, the higher the average household car ownership
2. There are large differences between parking standards and actual car ownership due to the following:
    a. Distance to train stations
    b. Parking permits (and their costs)
    c. Other influencing factors of car ownership at a specific location
3. In case people move from and to station areas, their car ownership will change as a result of a changed travel preference due to this move.
4. Based on the relationship between distance to train stations and other local aspects parking standards can be improved to more location-specific parking standards

3 Research questions and Scope

This section will introduce the research questions and the scope that gives guidance to this study.

3.1 Main question

This research aims to quantify the impact of train stations on household car ownership to improve parking standards in the Netherlands. The following research questions are the basis of this study:

Research Question	*What is the influence of proximity to train stations on household car ownership, and how can this relationship be used to improve parking standards in urbanised residential areas in the Netherlands?*

3.2 Sub questions

The first part of the main research question, the influence of train stations on household car ownership is the major part of the research. Not only the effect of train stations and other influencing factors on car ownership in one specific year is analysed, but the effects of changes in influencing factors too.

Q1	*What is the effect of train stations on household car ownership in urbanised areas?*

The first sub-question only focusses on the influence of train stations on household car ownership for one specific year. The influence of train stations on household car ownership is controlled by other influencing factors from socio-demographics and the built environment. Examples of these factors are age, income and parking permits.

Q2	*What is the effect of new train stations on household car ownership in urbanised areas?*

The second sub-question is about the influencing factors of changes in household car ownership. These relations will provide more insight into the effect of the train stations itself. Since possibly the residents of the new train station areas have not taken the train station into account in the location choice. On top of that, changes in the other influencing factors are analysed to find out which factors have the most explanatory power.

Q3	*How do household car ownership and travel behaviour differ between consonant and dissonant residents in areas with and without train stations in proximity?*

Sub question three focusses on the relation of preferences in location choice on household car ownership. The goal is to find out whether household car ownership differs among households that consciously chose to live in a train station area because of the train station. These results provide more insight for the parking policy at development locations at train station areas.

Q4	*How does car ownership change when people move to locations with different train station proximity than before?*

The next question is about the changes in household car ownership as a result of moving to areas with different proximity to train station. The results of this sub-question are used to get more insight into the extent to which the built environment has a decisive effect on household car ownership.

Q5	*Where do parking standards not fit the actual demand?*

The final part of the study is about the parking standards. According to the problem statement, there are situations that there is a possible misfit of parking standards with actual car ownership. Possibly, train stations are (partly) an explanation for this misfit. The goal of the fifth research question is to find out whether (the application of) parking standards can be improved in train station areas.

3.3 Scope

The main point of departure in this study is the train station proximity. Therefore, the focus of this study lies in train station areas. Only the built-up areas of the larger train municipalities are therefore a part of the study. Since the inclusion of those areas makes it possible to compare household car ownership in train-poor areas with train-rich areas. Furthermore, the time interval of the study has as a limiting factor the availability of data, which is 2005-2017.

Furthermore, the study utilises aggregated data and disaggregated data. The first data source is a land covering dataset and therefore provides a complete overview of the effects in the Netherlands. Nonetheless, the data source is limited because it assumes homogeneous aggregations. The second dataset is only a sample of the Netherlands and could, therefore, have representative and lack of data issues. The advantage is that this dataset includes more variation of households characteristics and includes travel preferences.

4 Methodology

The theoretical framework in Figure 4-1 shows the set-up of the research. This report includes a description of the results of the processes in this figure. This chapter contains the descriptions of the methods of the execution steps. The foundation of these steps lies in the literature study.

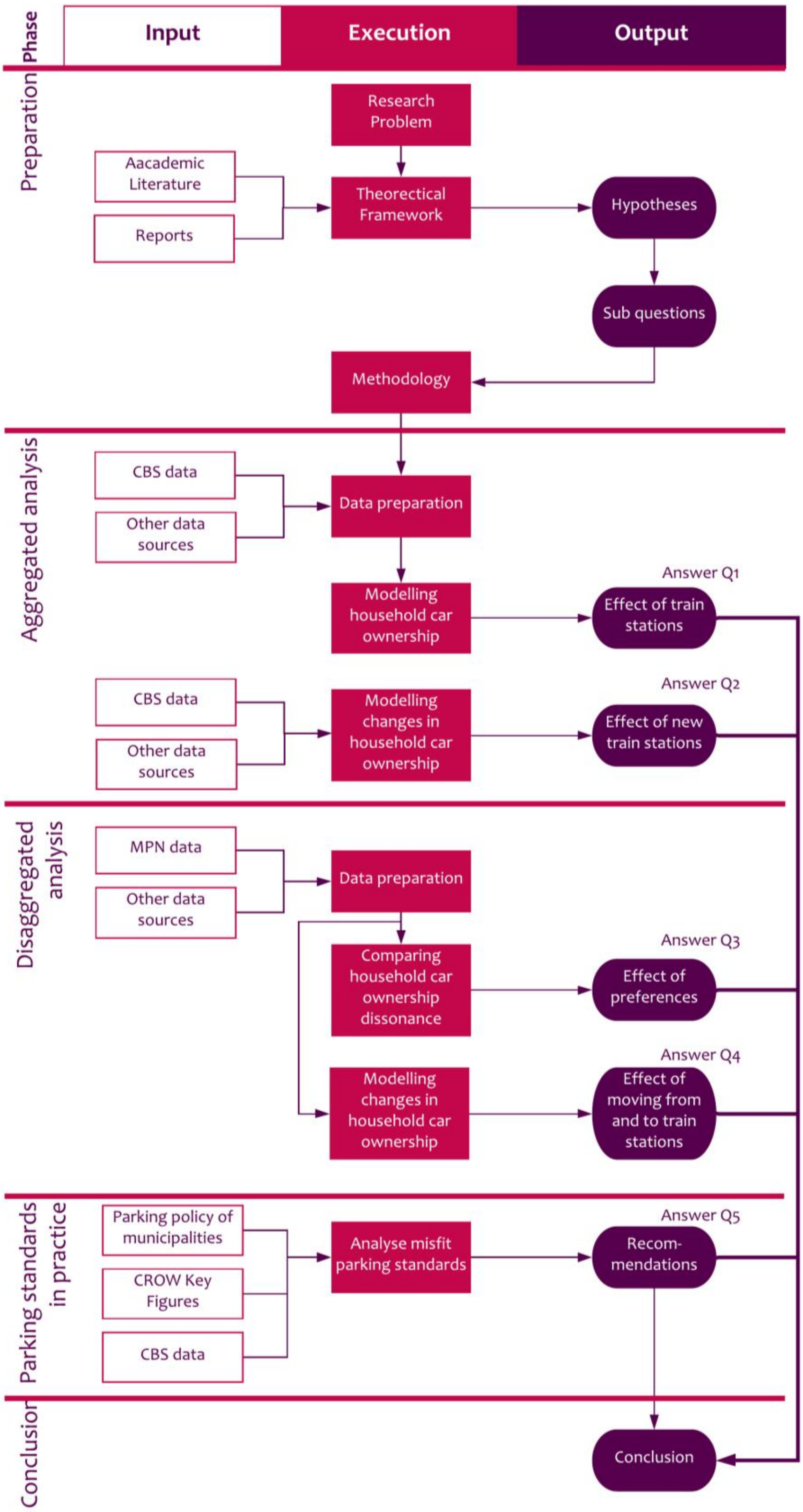


Figure 4-1 Theoretical Framework

4.1 Framework

Multiple data sources and methods are used to answer the research questions. The datasets CBS *buurt* data and MPN (the Netherlands Mobility Panel) form the foundation of the study. The first dataset is used to get more insights in average household car ownership in the whole country. This data source contains aggregated annual data about average household car ownership, built environment, socio-demographics and more for neighbourhoods of the whole country. The advantage of this dataset is that data is country-wide available, but the disadvantage is that the data is not on the household level. Therefore, the analysis bases only the results on averages of the neighbourhoods, which makes it impossible to take into account large differences within the neighbourhood and the individual preferences. On top of that, with aggregated data there is a risk of ecological fallacy: the conclusions may only be applicable for the neighbourhoods and not for the individuals.

To overcome these disadvantages, another dataset is used: a Dutch household panel which contains next to three days of travel diaries, (travel-related) background information of the household members: MPN. The surveys are at least yearly conducted among the same respondents. This repetition makes it possible to analyse the developments, in this case for household car ownership, as a result of influencing factors. The MPN datasets are used to find out whether either or both the built environment and travel preferences influence household car ownership. The advantage of this dataset is that now data is available on the household and individual level: there is more variation possible among households. Finally, this same dataset was used to again get more insight into the causal relations of train stations on household car ownership.

A summary of the advantages and disadvantages of the datasets is in the framework Table 4-1. These four datasets are all used in the report to finally quantify the influence of train stations on car ownership.

Table 4-1 Framework of methods and datasets with disadvantages and advantages

	Aggregated	**Disaggregated**
One year	<u>CBS *Buurt* data for 2016</u> + observed data + whole country - aggregated data -no personal preferences and attitudes - no development over time	<u>MPN data for 2014</u> - self reported data - sample + disaggregated data + includes personal preferences and attitudes - no development over time
Multiple years	<u>CBS *Buurt* data for 2005 - 2017</u> + observed data + whole country - aggregated data -no personal preferences and attitudes + development over time	<u>MPN data for 2013-2016</u> - self reported data - sample + disaggregated data + includes personal preferences and attitudes + development over time

4.2 Aggregated cross-section analysis

The cross-section analysis contains the analysis to relations of the influencing factors with household car ownership. The steps that finally lead to models explaining car ownership are discussed in this chapter.

4.2.1 Data preparation

Gross of the data of the for the cross-sectional analysis is obtained from CBS (Dutch national agency for statistics). Nonetheless, the CBS database did not contain all the required variables; therefore data is used from other sources too. After all the data is collected, the data must be on a comparable level of detail. Most of the data have the same neighbourhood level.

Nonetheless, not all data is aggregated to the appropriate level yet. Those data are prepared with ArcGIS, a computer program to visualise and analyse spatial data, to the same neighbourhood level. Only the neighbourhoods in the scope stay in the dataset for the analysis. An extensive description of the data is in shown in Appendix A.

Open source national data has several spatial detail levels. The chosen level of detail for this part of the study is "*Buurt*". That is a part of a municipality with a homogenous socio-economic structure or spatial planning (CBS, 2019). The boundaries of *buurten* are determined by municipalities, and the geographic administration is coordinated by CBS. Moreover, the detail levels are further described and compared in Appendix A.1. The year 2016 is the most recent year wherefore gross of the data is available and this year is included in the MPN data too. Therefore, the year 2016 is selected for the analysis.

The dataset contains three variables with information about car ownership: average household car ownership and the total number of cars in the *buurt*. The dependent variable is average household car ownership in the *buurt* because the total number of cars is strongly dependent on the size of the *buurt* and the number of cars per km^2 is strongly depended on the density of residents.

The variables that are available for the analysis of influencing factors of average household car ownership are listed in Table 4-2.The chosen variables are based on the literature review. If data was not available by CBS, data of other sources were prepared to the same detail level. Only national data about parking permits were not available, therefore is for every *buurt* in the neighbourhood, the website of the relevant municipality checked on price and requirement of parking permits. Enriched variables have a reference in the final column to the relevant section of the Appendix. Outliers were removed if the value for the variable was extreme (more than three times deviation of the mean) and if this record behaves as an influential outlier.

Table 4-2 Variables for cross-sectional analysis

Variable	Name in code	(Based on) source(s)	Detail level	Chapter of explanation
Average household car ownership	auto_hh	(CBS, 2016a)	*Buurt*	
Density				
Density of residents	bev_dichth	(CBS, 2016a)	*Buurt*	
Density of residents	bev_dich_wk	(CBS, 2016a)	*Wijk*	
Density of residents	bev_dich_gm	(CBS, 2016b)	Municipality	
Urbanisation level	sted	(CBS, 2016a)	*Buurt*	
Urbanisation level	sted_wk	(CBS, 2016a)	*Wijk*	
Urbanisation level	sted_gm	(CBS, 2016b)	Municipality	
Diversity				
Entropy index	Entropy	(CBS, 2015)	*Buurt*	A.3.2
Entropy index	Entropy_wk	(CBS, 2015)	*Wijk*	A.3.2
Job density	job_density	(Kadaster, 2018)	*Buurt*	A.3.3
Job- housing ratio	ratio_job_resident	(Kadaster, 2018) & (CBS, 2016a)	*Buurt*	A.3.3
Design				
Network distance to (nearest) strongly urbanised city centre	Netw_dist_centre_12	(Bikeprint, 2016)	*Buurt*	A.3.5
Centre, shell or other built-up area	Schil	(Bikeprint, 2016)	*Buurt*	A.3.5
Public Transport and Accessibility				
Nearest train station type	min_distance	(Prorail, 2019) & (Bikeprint, 2016)	*Buurt*	A.3.1
Distance to nearest train station	min_station_type	(Prorail, 2019) & (Bikeprint, 2016)	*Buurt*	A.3.1
Larger train station than nearest train station available in 3km	Larger			
Largest train station type in 3km	Largest			
Density of bus stops	bus_density	Goudappel Groep	*Buurt*	A.3.1
Bike and ride Accessibility	Average	University of Twente	PC4	A.3.1
Demand				
Parking costs	Parking	(RDW, 2018)	Parking area	A.3.6
Parking permits	Permit	Websites of municipalities	Buurt	A.3.7

Socio-demographics				
Percentage of households with lowest 40% of income	p_hh_li	(CBS, 2016a)	*Buurt*	
Percentage of people with income	p_inkont	(CBS, 2016a)	*Buurt*	
Average house hold size	gem_hh_gr	(CBS, 2016a)	*Buurt*	
Percentage of rental properties	p_huurw	(CBS, 2016a)	*Buurt*	
Average building value	woz	(CBS, 2016a)	*Buurt*	
Class of building value	price	(CBS, 2016a)	*Buurt*	A.3.4
Average income of residents	g_ink_pi	(CBS, 2016a)	*Buurt*	
Percentage of people with age between 0-14	p_00_14_jr	(CBS, 2016a)	*Buurt*	
Percentage of people with age between 15-24	p_15_24_jr	(CBS, 2016a)	*Buurt*	
Percentage of people with age between 25-44	p_25_44_jr	(CBS, 2016a)	*Buurt*	
Percentage of people with age between 45-64	p_45_64_jr	(CBS, 2016a)	*Buurt*	
Percentage of people with age 65+	p_65_eo_jr	(CBS, 2016a)	*Buurt*	
Average building year	Bouwjaar	(Kadaster, 2018)	Unit	A.3.4
Average surface area	average	(Kadaster, 2018)	Unit	A.3.4

4.2.2 Analysis of variables

The relations of the variables with household car ownership are analysed visually by creating bin plots and by creating maps in ArcGIS. Those plots provide more insight into the relations of the variables and are useful in comparison to the literature analysis but are not measures that can be used to quantify the relations.

Therefore, Pearson Correlation Coefficients (PCC) and their p-value are used to show which variables have a significant linear relationship with car ownership. The formula for the PCC is shown in Formula 4-1 (Zwillinger & Kokoska, 2000).

PCC
$$r = \frac{\left(\frac{\sum_i \left((x_i - \bar{x}) \cdot (y_i - \bar{y})\right)}{n-1}\right)}{\sigma(x) \cdot \sigma(y)} \qquad \text{4-1}$$

With i for the observation number, x and y for the two variables of interest and n the total number of observations.

For the categorical variables, the Spearman Rank Correlation Coefficient (SRCC) is a more appropriate measure. The formula for the SRCC is shown in Formula 4-2 (Zwillinger & Kokoska, 2000).

SRCC
$$r = 1 - \frac{6 \sum_i^n (u_i - v_i)^2}{n(n^2 - 1)} \qquad \text{4-2}$$

With u the rank of the i^{th} observation of the first variable of interest and v the rank of the i^{th} observation of the second variable of interest.

4.2.3 Regression models

The multiple linear regression models are used to analyse the selected variables in more depth. Since the results of the models show the effect of the individual influencing factors while controlling for the other factors. The estimation of the model is executed by Python Software with the module Statsmodels. As dependent variable, the estimated variable, average household car ownership is used. The models are built by step by step adding a new independent variable into the model: step-wise linear regression modelling. The variable with the largest impact on the residuals of the previous model will be added to the new model. Residual plots analyse this impact.

So, the output of the model is a continuous value for average household car ownership dependent on continuous and categorical influencing factors. The coefficients of the regression model will represent the strength of the relation between the variable and average household car ownership.

4.2.3.1 Formulas

A multiple linear regression model is used to model average household car ownership. The general formula is shown in Formula 4-3 (Zwillinger & Kokoska, 2000).

General formula $$\hat{y}_i = E(Y|X) + \varepsilon_i = \beta_0 + \beta_j x_{ij} + \cdots + \varepsilon_i \quad (4\text{-}3)$$

$\hat{y}_i$ represents the predicted value for the i^{th} observation. Dependent on β_0, the intercept or the constant and β_j the partial effect of variable x_{ij} on $E(y|x)$ with j for the (number of the) variable. So, β_j represents the effect of the change in x_j units while keeping the other independent variables constant. ε_i represents the error variable. The continuous variables can be used without dummy variables, but the categorical variables need dummies to be analysed. An important assumption of multiple linear regression models is that the independent variables have a linear relation with the dependent variable.

The ordinary least squares (OLS) is the chosen method for estimating the parameters. Therefore, the residual sum of squared (RSS) is minimised, see Formula 4-4. The residual is calculated by y_i: the actual value, minus $\hat{y}_i$: the predicted value.

RSS $$RSS = \sum_i (y_i - \hat{y}_i)^2 \quad (4\text{-}4)$$

To assess the goodness-of-fit of the regression, the R-squared value is used: the coefficient of determination. The R-squared value represents how the model can reduce many variations in the sample. Formula 4-5 shows how this value is calculated. The numerator of this formula is again the RSS, the total variation in the residuals, and the denominator of the formula represents the total variation in the sample.

R-squared $$R^2 = 1 - \frac{\sum_i (y_i - \hat{y}_i)^2}{\sum_i (y_i - \bar{y})^2} \quad (4\text{-}5)$$

4.2.3.2 Flowchart

The analysed relations of the factors are visualised in a flowchart in Figure 4-2. A the flowchart shows, the direct linear effect of the train stations, built environment and socio-demographics on average household car ownership are analysed.

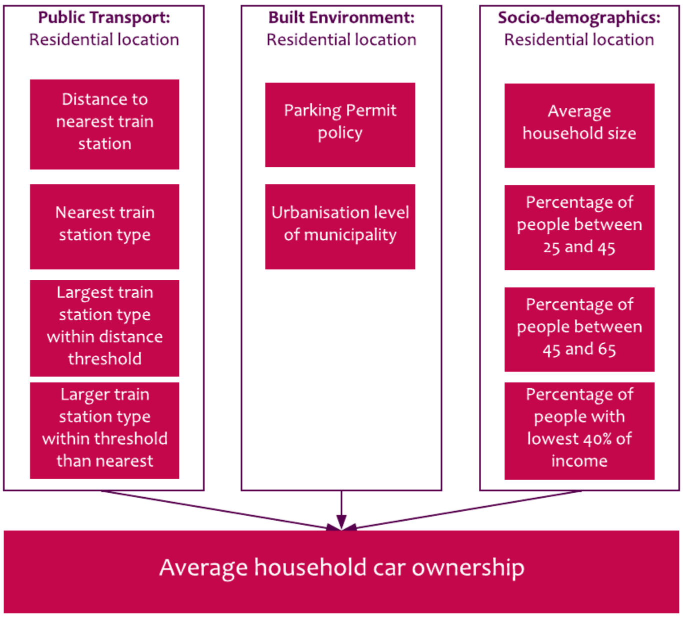


Figure 4-2 Flowchart of the aggregated cross-section MLR model

4.3 Aggregated data analysis over time

The next section will dive deeper into the causal effects of train stations on average household car ownership. The data sources for the analysis over time are similar to the cross-sectional study; only now, the data is available for the years 2005 – 2017. The data of the various years are matched based on the unique code of the *buurten*. Nonetheless, not all the neighbourhoods have stayed the same over the years. So, the *buurten* may have changed name or boundaries. In both cases, it is not possible to compare the *buurten* anymore. Therefore, is decided only to keep *buurten* in the dataset that did not change of code over time.

4.3.1 New train stations

The first analysis is about changes in average household car ownership as a result of the built of new train stations. Since the number of yearly new train stations are low, and the effects of changes may be slow. Therefore, there is decided to analyse the changes in average household car ownership over ten years. So, the dependent variable of the MLR model is the difference in average household car ownership between the years 2015 and 2005. The same variables as in the cross-section study are analysed as the independent variables. The changes in the years between 2015 and 2005 are analysed to explain the results of the MLR model.

4.3.1.1 *Models*

The formula for the MLR is comparable with the MLR from the cross-section. However, now the variables are time-dependent: they are the difference between 2015 (t_2) and 2005 (t_1).

General formula $$\widehat{y_{t_2} - y_{t_{1}}}_{i} = E(Y|X) + \varepsilon_i = \beta_0 + \beta_j(x_{ijt_2} - x_{ijt_1}) + \cdots + \varepsilon_i$$ 4-6

4.3.1.2 *Flowchart*

Again, the analysed relations are visualised in Figure 4-3.

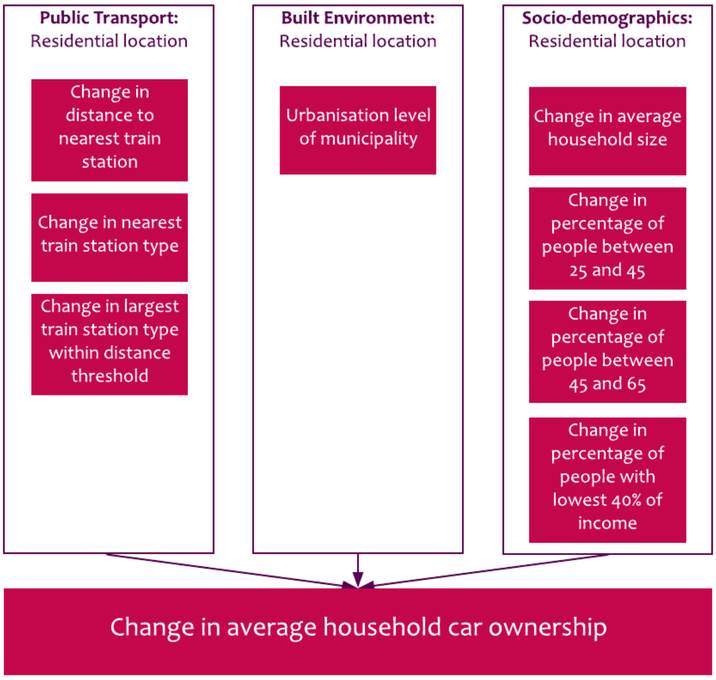


Figure 4-3 Flowchart of disaggregated analysis over time

4.4 Cross-section disaggregated analysis

The MPN-data is used for a cross-section analysis to find out the differences between dissonant and consonant residents. This data is acquired by the KiM Netherlands Institute for Transport Policy Analysis. KiM enriched the dataset with the influencing factors *buurt* data of the aggregated MLR models. About ten per cent of the respondents could not be enriched because either there was no data available for their residential area or changes in postal codes over time led no matches. To the continuous data was random noise of maximum ±1.5% added to guarantee privacy of the respondents' residential locations.

Both the difference between the built environment and difference in preferences is analysed to find out more about the self-selection effect. The corresponding flowchart is visualised in Figure 4-4. Both the difference in car ownership and composition of the population are compared.

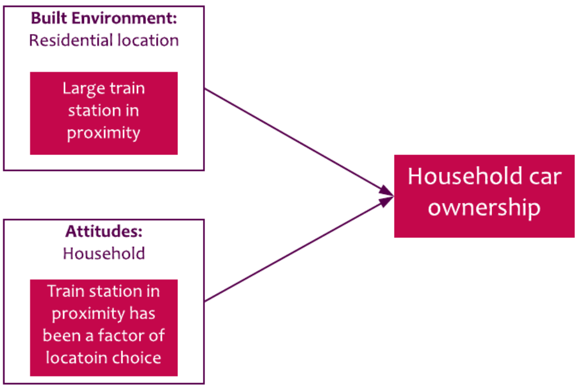


Figure 4-4 Flowchart Cross-section disaggregated analysis

4.4.1.1 Models

One-way ANOVA with posthoc Tukey HSD is applied to compare the differences in car ownership and travel behaviour among the groups of dissonant and consonant residents at different built environments. The one-way ANOVA reports if there are significant differences among the means of the treatment groups, whether the posthoc tests show which groups differ. Chi-square test is used to compare whether the treatment groups have a common distribution.

ANOVA F-statistic

$$F_0 = \frac{\frac{\sum_i(\widehat{y_i} - y)^2}{1}}{\frac{\sum_i(y_i - \bar{y})^2}{n - DF}} \quad (4\text{-}7)$$

The new variables are DF, which is the number of degrees of freedom and F_0, which is the F statistic.

Tukey HSD

$$q = \frac{\bar{y}_{max} - \bar{y}_{min}}{S\sqrt{2/n}} \quad (4\text{-}8)$$

With S the pooled standard deviation of the samples, n the number of observations and $\bar{y}_{max}$ the largest mean of the two samples that are compared and $\bar{y}_{min}$ the mean of the other sample. This test is used to test whether there are significant differences between pairs of the samples.

Chi-square

$$\chi^2 = \sum_i \frac{(O_i - E_i)^2}{E_i} \quad (4\text{-}9)$$

The chi-square test of independence is used to find out whether there is an association between the two variables. With O the observed value, E the expected and i the observation number.

4.5 Disaggregated analysis over time

Multiple years MPN-data are used to analyse the causal relations of train stations on household car ownership. Changes before and after the relocation of households are analysed to find out whether households change household car ownership as a result of changing from train areas. Due to the low amount of records, this analysis has a qualitative character. The analysed relations are visualised in Figure 4-5.

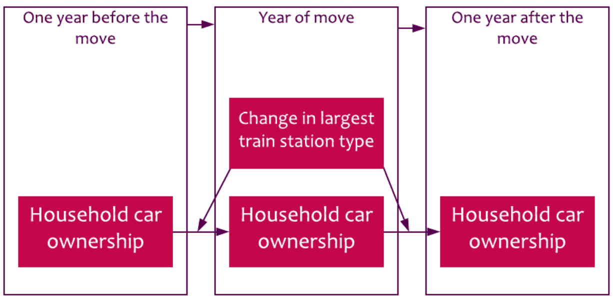


Figure 4-5 Flowchart Disaggregated analysis over time

4.6 The practice of parking standards

The practice of parking standards is analysed with three different steps:

1. Conversations with parking standards / key figures experts (reported in literature study)
2. Quick scan vision municipalities
3. Case studies

At first, are experts interviewed about the origin, development and application of the CROW Key figures. The goal is to find out how the key figures are intended to be applied. After that, a small quick scan to parking standards of municipalities is used to find out whether the key figures are used and how municipalities differentiate among locations and building types. Finally, two case studies are selected to compare the differences between actual household car ownership and the parking standards, actual household car ownership and the CROW Key figures to develop recommendations for improving parking standards. The case study selection is based on the characteristics of the neighbourhoods. For each neighbourhood in the case study are the current parking standards of the municipality estimated based on the current parking policy documents of the municipalities. Therefore are for each neighbourhood the applicable parking standards retrieved from parking policy of the municipality. Those parking standards are only applicable to new buildings and may not have been applied to the existing neighbourhoods. The same holds for the CROW key figures that are applied at the neighbourhoods in the sample.

5 Cross-section analysis of average household car ownership

This chapter analyses the possible influencing factors and quantifies the relation of train stations with average household car ownership. After the description of the data are the individual relations of the influencing factors briefly analysed. Then follow the results of the multiple linear regression models that are explaining average household car ownership. Finally, the results of the models are validated with an analysis of the residuals.

5.1 Data description

The data that of the cross-sectional analysis are CBS *buurt* data for the year 2016. The main scope of the analysis is the built-up areas of the larger municipalities. Therefore, the areas in the selection are at least moderately urbanised *buurten* in at least strongly urbanised municipalities. The selection of strongly urbanised areas is not only based on the scope but on the data too. Less urbanised municipalities are having a lower representativity of the neighbourhoods: the city centres are smaller and consist of just (a part of) a *buurt*. On top of that, on average the hardly any urbanised *buurten* have a larger surface area. This results in a dataset with almost all the extremely urbanised *buurten* of the Netherlands plus a lower proportion of the strongly urbanised and even smaller proportion of moderately urbanised areas see Figure 5-1.

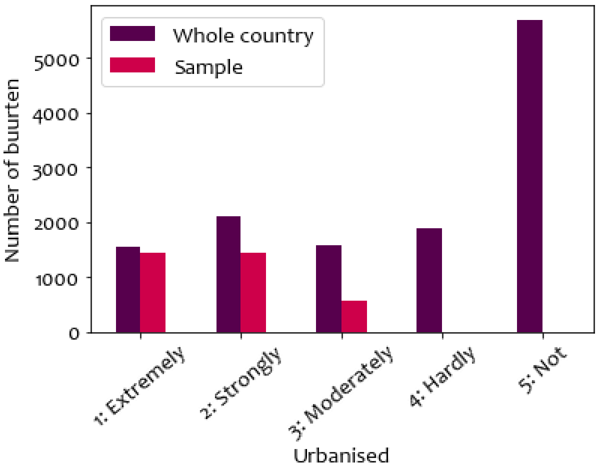


Figure 5-1 Comparison in urbanisation level of buurten

Although the sample is about a quarter of the *buurten* of the Netherlands, the sample contains about half the number of the Netherlands' residents. Likewise, the mean density of the sample is larger than the whole country; the sample is only about five per cent of the total land area. Table 5-1 shows a large variation in the number of the sample's *buurten* per Province. In particular, the provinces in the Randstad (polycentric urbanised concentration) have the largest proportion of the *buurten* in the sample.

Table 5-1 Data overview of the whole country and sample

Interest	Characteristic	The Netherlands 2016	Sample 2016
Buurten	Count	12822	3453 (27%)
Residents	Count	16.98 million	8.30 million (49%)
Land area	Sum	$337 \cdot 10^4$ ha	$16 \cdot 10^4$ ha (5%)
Density (residents/km^2)	Mean	2980	7049 (240%)
Province	Count		
Drenthe		663	44 (7%)
Flevoland		318	35 (11%)
Friesland		808	53 (7%)
Gelderland		1608	176 (11%)
Groningen		595	58 (10%)

Interest	Characteristic	The Netherlands 2016	Sample 2016
Limburg		901	190 (21%)
Noord-Brabant		1649	370 (22%)
Noord-Holland		1796	961 (54%)
Overijssel		1057	217 (21%)
Utrecht		857	297 (35%)
Zeeland		395	36 (9%)
Zuid-Holland		2175	1016 (47%)

5.2 Influencing factors

This section aims to get a better overview of the influencing factors of household car ownership. Appendix B consists of a more extensive description of the variables.

5.2.1 Train stations

This section will deepen into the main interest of the study: the relationship between the proximity to train stations and household car ownership. Not only the distance to the train stations is a part of the scope, but the service level of the train stations too. For example, the service level of a small train station with only two local trains in the hour is very low in comparison to a train station as Amersterdam Centraal with frequent intercity connections to almost all directions of the country. There are many parameters to describe train stations (connections, speed, frequency, etcetera) but the combination of those variables mostly explain the number of passengers at that train station.

Therefore, this report classifies the train stations in the number of passengers instead of a combination of explaining parameters. The classification of train station types is by the categories of Prorail, see Table 5-2. For the readability of the report, the train station types are referred in the text on a scale from large to small, see Table 5-2. This is not a reference to the actual size of the buildings but the number of passengers.

Table 5-2 Classification of train stations: station types in the categories of the number of passengers (Prorail, 2019)

	Type	Daily Passengers	Examples	Tekst reference
1	Cathedral	> 75 000	Amsterdam Centraal, Utrecht Centraal	"largest train station type"
2	Mega	25 000 – 75 000	Amersfoort, Zwolle	
3	Plus	10 000- 25 000	Maastricht, Almelo	
4	Basis	1 000 – 10 000	Dronten, Enschede Kennispark	
5	Stop	< 1 000	Arkel, Hoevelaken	"smallest train station type"

Train stations and average household car ownership are visualised in Figure 5-2 for the polycentric area Randstad. The visualisation indicates that neighbourhoods near the largest train station (Cathedral) have the lowest household car ownership, while neighbourhoods near the smallest train stations (Stop) have the highest average car ownership per household. Furthermore, the city centres of the four large cities in Figure 5-2 contrast sharply by the relative low household car ownership in comparison to the other cities. It is striking that not only the area near the train stations but the centres of the cities have on average very low household car ownership in comparison to the other areas.

The goal is to finally quantify the relationship between proximity to train stations and household car ownership. Therefore, for each *buurt* in the dataset, variables are constructed that describe the train stations in their neighbourhood. The goal is to include both the type of the train station and the distance to the train station in the analysis. Thus, for each *buurt* the bike distances to each train station in the Netherlands are determined by the Network Analyst of the software ArcGIS. This results in an OD matrix with bike distances from each centre point of the *buurt* to each train station. From this matrix are variables constructed like bike distance to nearest train station, nearest train station type and largest train station type within a distance threshold.

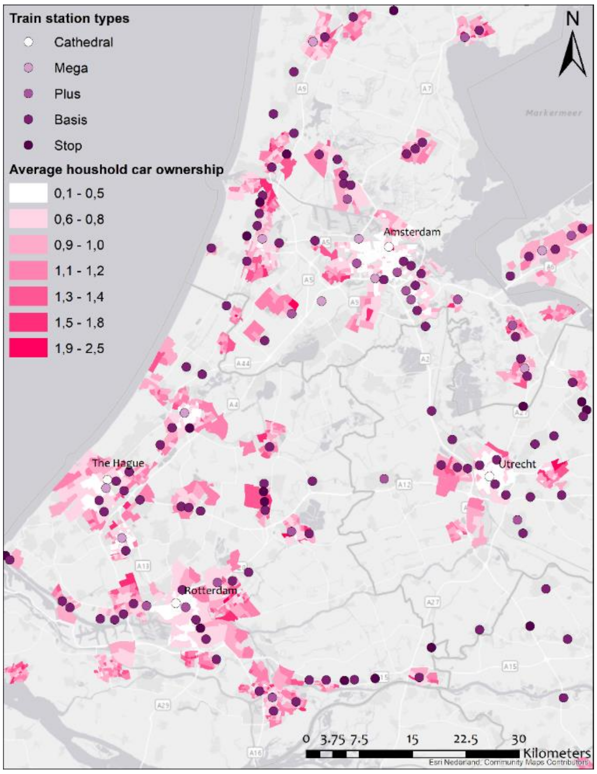


Figure 5-2 Average household car ownership and station types in Randstad. Data by (CBS, 2016a) and (Prorail, 2019), processed by the author.

The quantification confirms the visual expectations in Figure 5-3. From there follows that the larger the distance to the train stations, the higher the average car ownership of the *buurt.* Not only the distance to the train stations seems related to car ownership, but the type of the train station too. Figure 5-4 shows that neighbourhoods that have as nearest train station Cathedral or Mega have lower car ownership near to the train station in comparison to the other train station types. An explanation is that there are hardly any neighbourhoods in the dataset with large distances to the larger train stations. Neighbourhoods with lower proximity to a large train station are more likely to be located near smaller train stations see Figure 5-2. On top of that, neighbourhoods with larger distances to smaller train stations are more likely to be in areas with lower proximity to any train station at all.

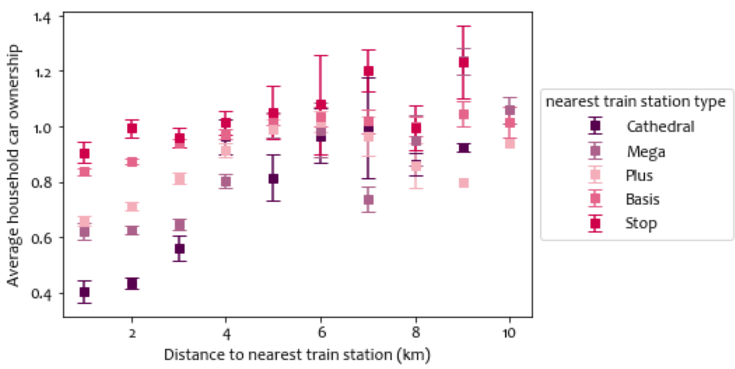


Figure 5-3 Average household car ownership for the aggregated distance to nearest train station per type and standard error

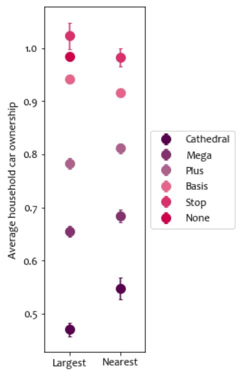


Figure 5-4 Average household car ownership per train station type for the two variables: largest train station type within 3km and nearest train station type

5.2.2 Built environment and socio-demographics

The previous section showed that household car ownership is lower in areas near (large) train stations. Nonetheless, now should be investigated whether this relationship holds while controlling for other influencing factors. Therefore, this section analyses the relationship of the variables with household car ownership. For each variable, the correlations and p-values are determined, and the relations with average household car ownership are visualized as in Table 5-3. Table 5-4 provides an overview of the significantly associated variables with household car ownership. Whereas the percentage of people with the lowest 40% of income has strong relation with household car ownership, there are more variables with strong relations with average household car ownership.

As followed by the literature analysis, the household size has a positive relation with household car ownership. Similarly, in this dataset, the average household size strongly positively correlated with average household car ownership. This effect may have two reasons: adult couples have, on average, more cars than adults single-person households and couples with children have on average higher car ownership than couples without children.

From the visual inspection of Figure 5-2 follows that there might be a strong relationship between the city centre and car ownership too. When the distance to the city centre increases, average household car ownership decreases. Nonetheless, from Table 5-4 follows that this relation is not the strongest relationship between the factors and car ownership and this relationship may have its origin by other factors that are not in the analysis.

The relation between income and household car ownership seems more obvious; the more people with low income, the lower is their average household car ownership. The costs of owning a car can explain this relationship, probably people with the lowest 40% of income do not have enough money to afford a car or have other priorities for their budget.

The parking permits originate from the policy reports regarding parking permits of the municipalities in the sample. The costs and the areas are manually retrieved from the policy documents and applied on the buurten of the sample. Figure 5-5 shows that the costs of the parking permit differ largely in the country among the municipalities. Striking are the large differences in costs. Although most of the parking permits are between zero and a hundred euros per year, there are even *buurten* with costs over 300 euros per year. The prices and maximum number of the parking permits seemed in most of the municipalities correlated with the capacity in the neighbourhood and whether in the area should be paid for parking. In the smaller municipalities are these areas in the centre and sometimes the surrounding neighbourhoods. In the larger municipalities are on a large extent parking permits applied to the built-up area.

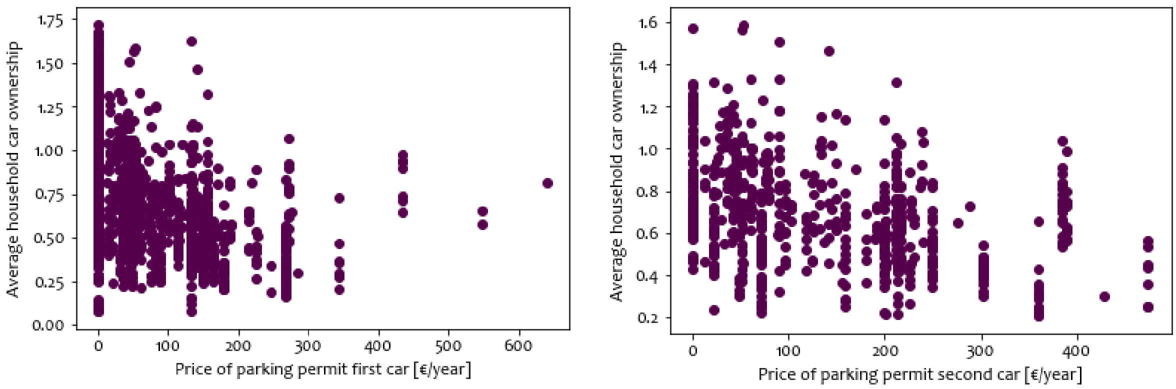
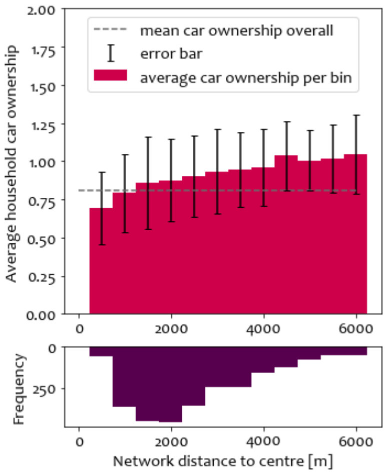
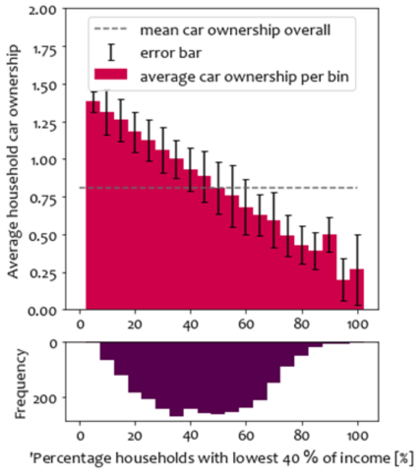


Figure 5-5 Prices of parking permits for a first and second car versus average household car ownership

Table 5-3 Relations of car ownership with distance to the city centre and income



Corr: 0.31 , p-value = 0.00



Corr: −0.82 , p-value = 0.00

Finally, the urbanisation level of the *buurt* has a stronger relation with average car ownership than the urbanisation level of the municipality. Still, both variables are positively associated with average car ownership: the stronger the urbanisation level, the lower car ownership. For this association should be noted that the number representing the urbanisation level increases when the urbanisation itself decreases. Appendix B contains a more thorough analysis of the variables that are and are not described in this section.

Table 5-4 Relations of selected possible influencing factors on car ownership

Type	Variable	Corr*	Direction	Symbol
Density	Density of residents	-.42	-	D
	Urbanisation level	.56**	+	
	Urbanisation level of municipality	0.35**	+	U
Diversity	Job density	-.37	-	J
	Job- housing ratio	-.20	-	
Design	Network distance to city centre	.31	+	Cd
	Centre, shell or other built-up areas	.19	+	
	Average building year	.41	+	
Demand	Parking Costs	-.38	-	
	Parking Permit	-0.47**	-	Pc
Public Transport and Accessibility	Nearest train station type	.27**	+	T_{type}
	Distance to nearest train station	.29	+	Td
	Bike and ride Accessibility	-.26	-	A
	Largest train station type within 3km	-.53**	+	L_{type}
	Larger train station type within 3km	0.21**	+	LT
Socio-demographics	Percentage of households with the lowest 40% of income	-.82	-	I
	Average house hold size	.77	+	S
	Percentage of rental properties	-.75	-	
	Average building value	.52	+	
	Class of building value	.42**	+	
	Average income of residents	.46	+	
	Percentage of people with age between 25-44	-.46	-	P25

Type	Variable	Corr*	Direction	Symbol
	Percentage of people with age between 45-64	.61	+	P45
	Average surface area	.66	+	
	Percentage multi-family housing	-.70	-	

* Pearson Correlation Coefficient: all variables have a p-value ≤ 0.001
** Spearman Rank Correlation Coefficient: with p-value ≤ 0.001

For each variable, scatterplots and single linear regressions are analysed to investigate the assumption of linearity. In the example in Figure 5-6, the scatterplots of the percentage of rental properties and the percentage of people with the lowest incomes have a similar relation with average household car ownership. Nonetheless, the relation with the income variable is stronger, and R^2 is higher than the percentage of rental households. Probably, the percentage of rental properties represents or is a result of the income variable; people with the lowest income are probably more likely to live in rental properties (Pearson's Correlation Coefficient: 0.88). Which might explain a larger variation for the relation between average household car ownership and rental properties. Although not every variable has a high correlation with average household car ownership, it seems that the assumption of linearity suffices for gross of the variables.

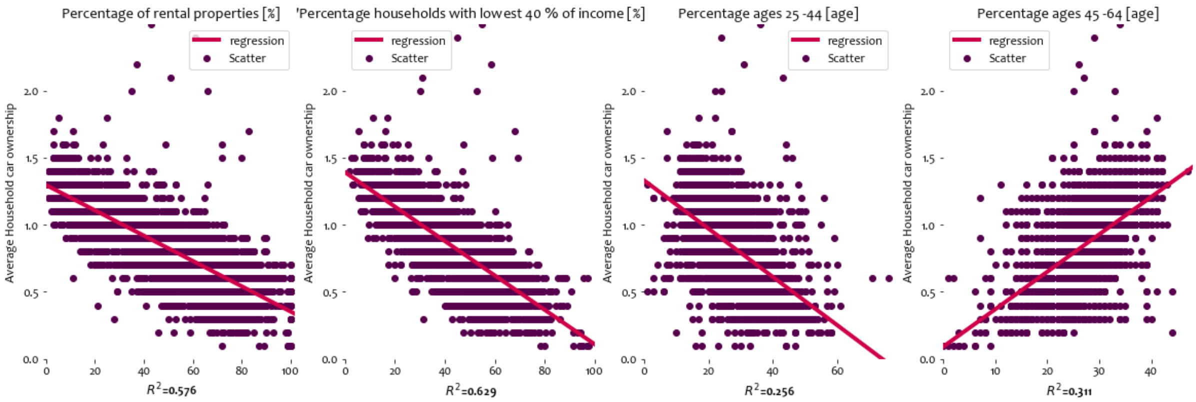


Figure 5-6 Scatterplots with single linear regression lines and coefficient of determination (R^2)

All the variables in Table 5-4 cannot simply be put in a multiple linear regression model yet. To prevent high multicollinearity between the analysed variables, strongly interacting variables should be discarded. Evidently, variables representing the same value are highly correlated; for example, there is a high correlation between average house value and the relative house value (cheap, middle, expensive) to the municipality. Apart from that, other variables are highly correlated while they do not have identical representations. There is, for example, as already mentioned, a high correlation between the percentage of residents with the lowest 40% of income and the percentage of rental properties. Both variables seem to have a comparable relationship with average household car ownership. In other words, the percentage of rental properties represents the income level with more variation than income itself. This also holds for the average house value and house area. So, there is assumed that the choice for housing is a result of the socio-economic status of the residents. The interacting variables with the strongest relations with average household car ownership are reserved for the analysis. Those variables have a symbol in Table 5-4.

5.3 Multiple Linear Regression models

The results of the multiple linear regression models are displayed in Table 5-5. Model A consists only of four socio-demographic variables. As expected, the variable the percentage of households with the lowest 40% of income has the strongest relation with average household car ownership. In the second model, the built environment variables are added into the model too. From the literature study followed that demand lowering measures lead to lower car ownership. This agrees with the effect of parking permits. The more limitations by the parking permit, the lower average car ownership. This only doesn't hold for the price of the second parking permit: there is no significant difference among the cheap, middle and expensive parking permits. Nonetheless, there is a significant difference between the possibility to have a parking permit for two cars or more and only one car.

The two base models A and B didn't contain train station variables yet. Figure 5-7 shows the average residuals of model B for the nearest train station types and the aggregated bike distance to the train stations. From that place can be concluded that still holds that the larger the distance to the train stations the higher the average household car ownership. On top of that is average household car ownership overestimated for distances to the nearest train station smaller than three kilometres. Figure 5-8 shows that the largest average residuals are at the extreme train stations: Cathredral and Stop. Although the residuals are not large and Table 12-3 in Appendix A.3 shows that the number of *buurten* with Cathedral and Stop as nearest train station are not the most frequent, the train station types may predict the extrema in household car ownership.

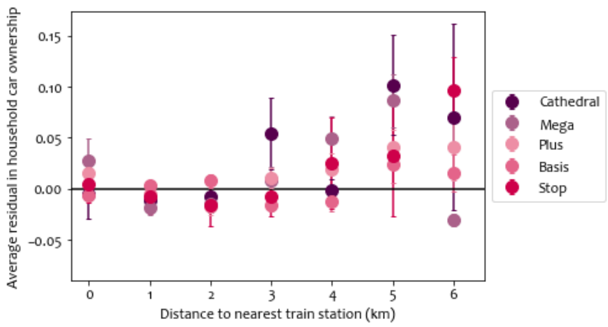


Figure 5-7 Average residuals per aggragated distance

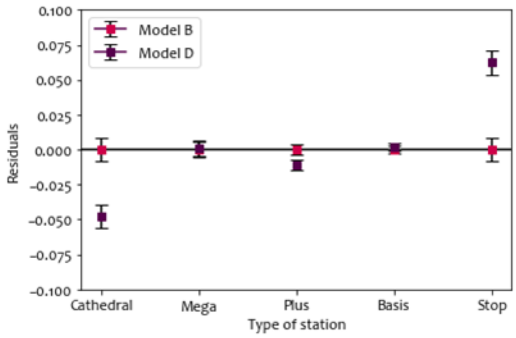


Figure 5-8 Average residuals per nearest train station type

While model C only includes one variable, model D includes more variables to better get insight into the effects of train stations. Model C with train station variable the largest train station type within 3km bike distance from the centre of the *buurt* seems to have to same explanatory power as model D with the three train station variables. In comparison to the other train station types, neighbourhoods with a Cathedral at proximity less than 3km have lower car ownership. Surprisingly, there is no significant difference found in average household car ownership in *buurten* with a Stop train station as largest train station in 3km and *buurten* without any train station within the distance threshold. Two reasons could explain this: either both are more near the periphery of the towns or the smaller train stations do not have enough connectivity to job or recreational destinations.

Model D confirms the earlier descriptions of the variables: the larger the nearest train station type, the lower average household car ownership and the larger the distance, the larger the average household car ownership. Only there is not a significant difference between the Mega and the Plus train station type. On top of those relations, the results of the multiple linear regression model show that the average household car ownership is lower when within 3km there is a larger train station type accessible. This indicates that not only the nearest train station influences average household car ownership, but the train stations that are within a distance that people are willing to bike. This could be explained by the fact that a higher number train stations in the neighbourhood increase the possibilities to reach destinations. On top of that, this could be in agreement with the literature that people are willing to bike to a train station further away to go to an intercity train station.

Table 5-5 Results Multiple Linear Regression models (Coefficients) and standardised results (Beta)

Dependent variable: **Average household car ownership**	**Multiple Linear Regression models – Cross section study 2016**							
	A Socio-demographics (SD)		**B** SD + Built environment (BE)		**C** SD + BE + Public transport		**D** SD + BE + Public transport	
Variables	Coef.	Beta	Coef.	Beta.	Coef.	Beta	Coef.	Beta
Constant	0.8882	-9.975E-18 *	0.9844	-0.1128	1.0371	0.0125	0.9278	-0.3497
Built environment								
Urbanisation level Municipality (ref. = 1)								
2. Level 2			0.0988	0.3450	0.0841	0.2934	0.0804	0.2807
Parking Permit (ref. = no parking permit required)								
2. Permit: 2nd car cheap			-0.0672	-0.2347	-0.0461	-0.1608	-0.0489	-0.1706
3. Permit: 2nd car middle			-0.0633	-0.2208	-0.0553	-0.193	-0.0511	-0.1782
4. Permit: 2nd car expensive			-0.0846	-0.2952	-0.0582	-0.203	-0.0642	-0.2241
5. Permit: No 2nd car allowed			-0.1833	-0.6397	-0.1516	-0.5292	-0.1577	-0.5505
Public transport								
Nearest train station type (ref. = Cathedral)								
2. Mega							0.0654	0.2283
3. Plus							0.0622	0.2170
4. Basis							0.0903	0.3151
5. Stop							0.1662	0.5802
Distance to nearest train station							0.0036	0.0413
Is nearest train station the largest train station within 3km? (ref. = Yes)								
2. No							-0.0443	-0.1546
Largest train station type within distance threshold (ref. = No train station)								
1. Cathedral					-0.1334	-0.4657		
2. Mega					-0.0501	-0.1749		
3. Plus					-0.0487	-0.1700		
4. Basis					-0.0195	-0.0681		
5. Stop					0.021*	0.0732*		
Socio-demographics								
Percentage of lowest 40% income	-0.0075	-0.4747	-0.0086	-0.5424	-0.0087	-0.5479	-0.0087	-0.5478
Average household size	0.2186	0.2934	0.11	0.1476	0.0893	0.1198	0.098	0.1316
Percentage of age 25-44	-0.0087	-0.2626	-0.0044	-0.133	-0.0035	-0.1071	-0.0039	-0.1199
Percentage of age 45-64	0.0022	0.0464	0.0031	0.0668	0.0034	0.0718	0.003	0.0629
	R^2	0.787	R^2	0.844	R^2	0.854	R^2	0.854
	σ_{est}	0.132	σ_{est}	0.113	σ_{est}	0.110	σ_{est}	0.109

All coefficients and betas are significant at 99.9% confidence interval (p<0.001) except of the values with:
*** Insignificant at 99.9% and 95% confidence interval (p>0.05)**

In concluding, the results of the standardised multiple linear regression (the Betas) show that income, limited parking permits and the Cathedral within 3km have the largest effect on average household. Although the addition of the train station variables did not improve the model to a large extent, the train station types seem to better predict the extrema in average household car ownership.

5.4 Residuals

Finally, the residuals are analysed to find out why and when the model is not able or not exactly enough to predict average household car ownership. The standard error of the estimate of the final model was 0.109. This means that the actual value with a 95% confidence interval will approximately fall in an interval of the estimated average car ownership plus and minus 0.214 (1.96* σ_{est}). The residuals that did not fall in that interval are visualized in Figure 5-9. At both the map of the Randstad as map of the South of the Netherlands dark pink areas attract the attention: the underestimations of the model. Likewise, in the scatterplots of average household car ownership in Figure 5-6 were striking outliers with high average household car ownership too. So, it seems that the model is not able to predict those extrema. On the other hand, there are areas with overestimations of the model too. It seems that *buurten* with overestimations are clustered in municipalities or larger neighbourhoods.

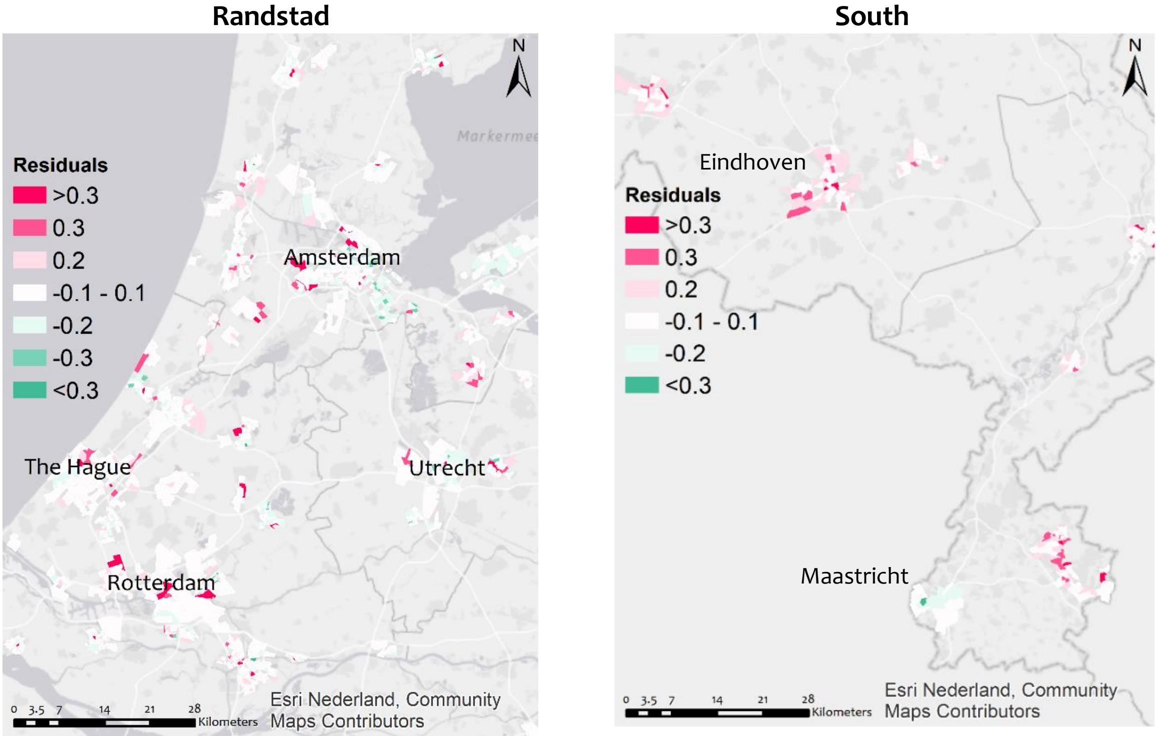


Figure 5-9 Residual plots of Multiple Linear Regression Model D (pink for underestimations, green for overestimations of the model)

One striking similarity for gross of the extreme underestimations is the presence of a hospital or furniture heaven. In both cases the buildings themselves might not be the cause of the above-average household car ownership but may have a relation with car accessibility. Since hospital and furniture heavens are located at high car accessible areas. On top of that, those areas might have a more spacious layout, which may result in a higher parking capacity and therefore lead to higher average household car ownership.

Municipalities have either clustered underestimations or overestimations with some extreme residuals. These clusters might indicate that an influencing factor of that area is not included in the model. For example, Maastricht has a large overestimation cluster which can be explained by the relatively large number of students in the city. Since students have on average the lowest average household car ownership. Gross of the municipalities in Noord-Brabant and Limburg have clustered underestimations; those might be explained by their residents' travel preferences or socio-cultural background. More explanations of differences among municipalities might be the parking or car policy or political preferences.

5.5 Conclusion

In many literature studies, the effect of train stations on car ownership is measured by the relations between the distance to a train station and household car ownership. From those studies followed that the effect of train stations varies from non-significant to a negative effect. In this report, the aim was to quantify the relation between household car ownership and train stations for urbanised areas in The Netherland. This chapter showed that not only the distance to a train negatively affects household car ownership, but the type of the train station too.

Especially, there is a difference between a small train station with a maximum of 1000 daily passengers and a large station with on average more than 75.000 daily passengers. The accessibility could explain this difference: the large train station will have more time and destination options to travel than a small train station with only one regional stopping train twice an hour. Plus the smaller the distance to a train station, the larger the possibility the residents will travel by train. Not only the nearest train station is negatively associated with average household car ownership, but train stations within a distance people are willing to travel too.

Although the difference seems not very large: 0.16 cars per household, in the development of a large residential apartment complex in the inner city of for example Utrecht this could have a large impact. With expensive building ground and parking garages below ground level, the building costs of one parking place maybe thirty to fifty thousand euros (BPD, 2018). In an apartment complex of 100 residences, this difference is already a difference in costs of five to eight hundred thousands of euros.

In studies to household car ownership, the effect of the socio-demographics and the built environment are extensively analysed. In this chapter the limited parking permit, low income and the largest train station type seem to have the largest effect on average household car ownership in the standardised multiple linear regression model. Relatively new in studies on car ownership is the impact of parking permits. Although the negative effect of a parking permit was according to the hypothesis, the non-significant difference in car ownership in the price of the second parking permit was not. The study showed that not the price, but the number of maximum allowed parking permits is an important factor in household car ownership. This can explained by the large differences in prices per municipality for parking permits. So, in this study the socio-demographics and the built environment have an important explanatory power.

Nonetheless, the cross-sectional method does not provide insights into the causality. Although the train station types seem to have an import influence, the results do not show whether household car ownership changes due to for example a new train station or a move to a train station area. Therefore, the following chapters will go deeper into the causality question.

Q1	*What is the effect of train stations on average household car ownership in urbanised areas?*

In the cross-sectional aggregated analysis for the year 2016, the proximity to train stations has a significant negative effect on average household car ownership. This relation even holds while controlling for other influencing factors of socio-demographics and built environment. The train stations were expressed in the following variables:

- Minimum distance (bike distance to nearest train station)
- Nearest train station type (category of daily passengers of a train station that is at the smallest bike distance from the centre of the neighbourhood),
- The larger train station (whether there is a train station with more daily passengers in a bike distance of three kilometres of the centre of the buurt)
- Largest train station type (the train station in the category with the most number of daily passengers within a bike distance of 3km from the centre of the buurt).

The variable with the classification of train stations in daily passengers in the proximity of three kilometres is analysed in a separate multiple linear regression model. The following conclusions are:

- *The larger the distance to the nearest train station type, the larger the average household car ownership. However, this effect is marginal in comparison to other influencing factors.*
- *The effect of train station types differs: especially there is a large difference between the train station category with the most and the least number of passengers. For example, average household car ownership in a neighbourhood near the central train station in Amsterdam is 0.17 lower than a comparable neighbourhood with a small train station type as the nearest train station, for example, Hengelo Gezondheidspark.*
- *In case there is a larger train station than the nearest train station in a bike distance of three kilometres, the average household car ownership in those areas is even smaller.*
- *The train station in a bike distance of maximum three kilometres in the category of the highest number of daily passengers has the largest effect on average household car ownership: in comparison to no, or the lowest category is average household car ownership about 0.14 lower.*

So, in general, have train stations a negative effect on average household car ownership in urbanised areas.

6 Aggregated longitudinal analysis

This chapter describes the influencing factors of changes in average household car ownership over about twelve years. The goal is to find out whether the arrival of train stations influences household car ownership, to provide more insight into the causal relationship between average household car ownership and train stations.

6.1 Data description

Because not all neighbourhoods are available for the years of interest, the data sample of the aggregated longitudinal analysis is slightly smaller than the dataset of the cross-sectional study. The main reason for this lower availability is the change of the codes of the *buurten* or geographic changes in boundaries of the *buurten*. Table 6-1 shows the distribution of the sample. The oldest CBS *buurten* dataset originates from 1995. However, the datasets before the year 2005 do not contain the required variables yet. Therefore, this dataset contains uneven years between 2005 and 2017.

Table 6-1 Data overview of the whole country (2016) and sample (2005-2017)

Data	Characteristic	The Netherlands in 2016	Sample 2005-2017
Buurten	Number of occurrences	12822	2209 (17%)
Residents	Number of occurrences	16.98 million	5.79 million (33%)
Land area	Sum	337 ·10⁴ ha	11 ·10⁴ ha (3%)
Density (residents/km²)	Mean	2980	6575 (221%)
Province	Number of occurrences		
Drenthe		663	0 (0%)
Flevoland		318	30 (9%)
Friesland		808	20 (2%)
Gelderland		1608	132 (8%)
Groningen		595	34 (6%)
Limburg		901	107 (12%)
Noord-Brabant		1649	239 (14%)
Noord-Holland		1796	403 (22%)
Overijssel		1057	168 (16%)
Utrecht		857	257 (30%)
Zeeland		395	28 (7%)
Zuid-Holland		2175	791 (36%)

6.2 Influencing factors over time

The cross-sectional study in Chapter 5 showed that on average people living near the largest train station have the lowest car ownership. In agreement, the graphs in Figure 6-1 show the same relations over the years, with no clear trends in average household car ownership per train station type. Although, neighbourhoods near the largest train station types (nr. 1 and 2) do not follow the trend of increasing household car ownership. The graph on the right clearly shows that there has never been a significant difference between a stop and no train station within three kilometres over the years. In general, the effects of train stations seem not to have changed over time.

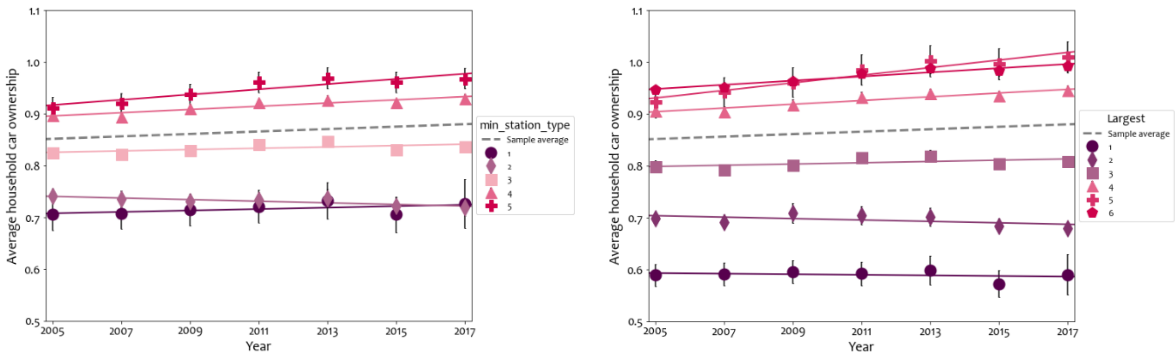


Figure 6-1 Relation between average household car ownership and train stations types over the years. Left figure: nearest train station type, right: largest train station type within 3 km.

Nonetheless, this is in contrast with the socio-demographic variables of the age categories, see Figure 6-2. Still holds the more people between 45 and 64, the higher the average household car ownership. However, now it seems that there is an increase in average household car ownership in neighbourhoods with a relatively high amount of people with age between 45 and 64 over the years. The latter is in agreement with the described trends in the literature analysis: older adults tend to have on an increasing household car ownership, and the younger adults tend to have decreasing household car ownership. Appendix E shows that the results of the cross-sectional study in 2016 are representative for the other years too.

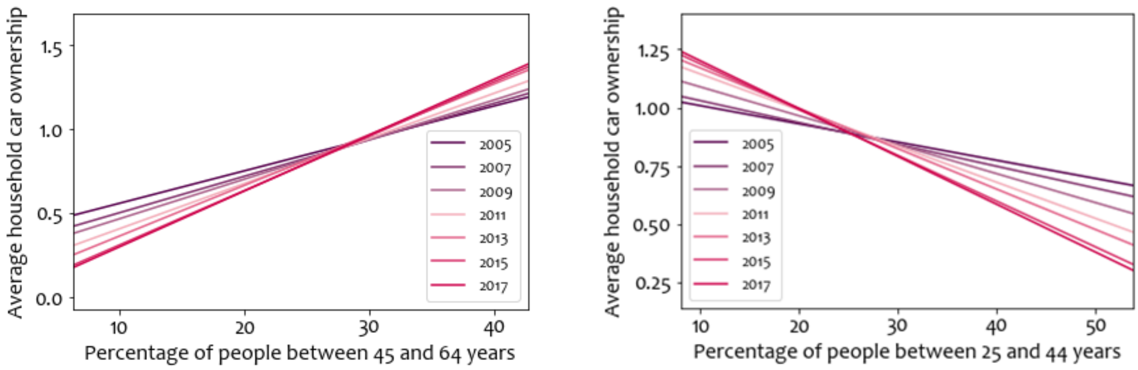


Figure 6-2 Relation between average household car ownership and percentage of people between 45 and 64 over the years. (For readability: Results of simple linear regressions with average household car ownership per year)

In summary, not only the composition of the neighbourhoods has changed over the years, but the effects of the influencing factors on car ownership too. Therefore, the developed models for the year 2016 are possibly not directly applicable to the previous years.

6.3 Trends in influencing factors

The previous section showed that the models of 2016 might not be applicable for the earlier years. Therefore, this section dives into the multiple linear regression models of the years between 2005 and 2017 to analyse trends in household car ownership and its influencing factors, before the effects of the arrival of train stations are determined.

Cross-sectional MLR models are constructed for the uneven years to find out whether the effect of the variables has changed over time. The most striking effect is the influence of parking permits. What clearly can be seen in Figure 6-3 is that the influence of parking permits has changed over the years; this figure shows the standardised coefficients for the MLR models. Areas with parking permits in 2019 possibly did not have parking permits in the earlier years. Therefore, the changes in parameters may indicate that the introduction of parking permits has decreased average household car ownership.

The effect of the largest train stations has increased over the years, see right upper graph in Figure 6-3. In the graph of the socio-demographics variables has especially the influence of the percentage of lowest forty per cent of income negatively increased. Contrary, the effects of the other socio-demographic variables seem to have decreased.

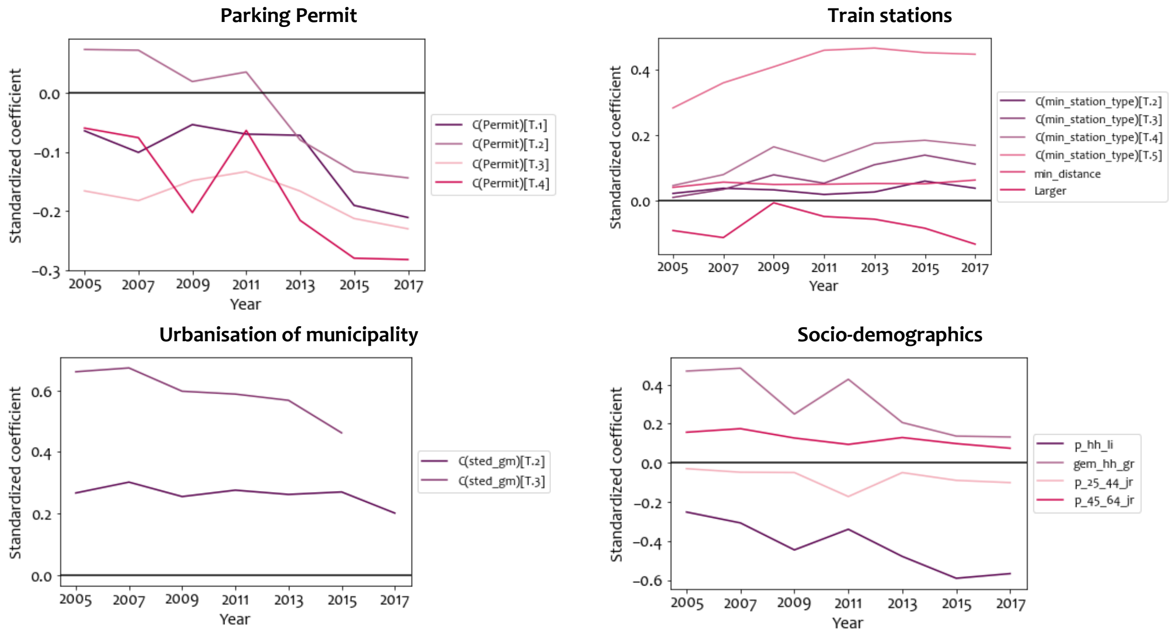


Figure 6-3 Standardized coefficients over the years in cross-sectional multiple linear regression models per year

Not only the effect of the factors may have changed, but the proportions of specific population may have changed too. From the literature study followed three specific trends: a sharp rise in the ageing population, an increase in car ownership among older adults and a decrease in car ownership among young adults. Figure 6-4 shows the trends among the different age categories in the Netherlands. Therefrom follows that both the number of older people as the average household car ownership among these groups is increasing. Most striking are the groups with ages over the 50 and especially the group of 65+; those groups have a strong increasing household car ownership.

Figure 6-4 does not show a confirmation of a decreasing trend in car ownership among the youngest adults. A probable explanation may be the household size: when household car ownership does not change, but the household size decreases, then does average household car ownership increase per household member. Still, there is a clear negative trend in household car ownership in the age groups 30-40 and in the later years of the age group 40-50. These effects may indicate or average household car ownership decreases among the age group 30-50 or the generation of 30-40-year-olds in the zeros and 40-50 ten years later has on average lower household car ownership than the previous generations.

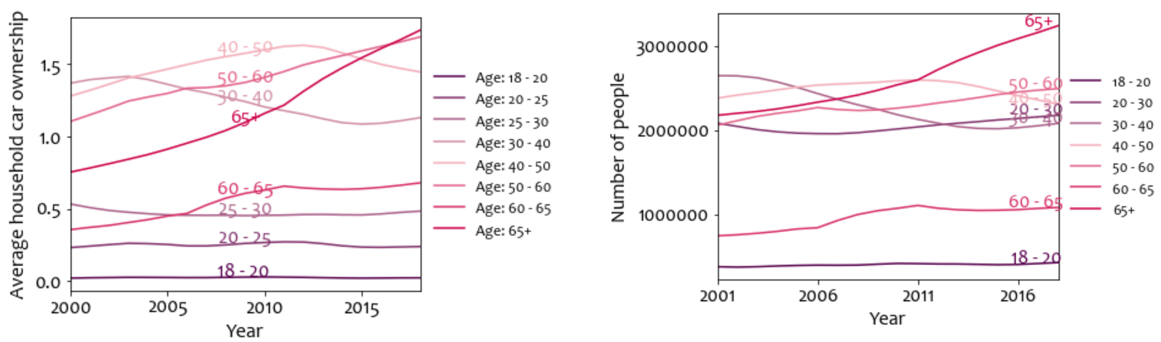


Figure 6-4 Trends in average household car ownership and group sizes

In general, over the years are not only changes in household car ownership and its influencing factors but are changes in the compositions of the households too. Therefore, the analysis of the arrival of train stations should control for changes in influencing factors too.

6.4 Changes in nearest train stations

In the years between 2005 and 2015 were in total 41 new train stations opened. Those new train stations were either the type Stop or Basis. However, only for eighty of the neighbourhoods in the selection, one of the new train stations was nearer than the other already existing train stations.

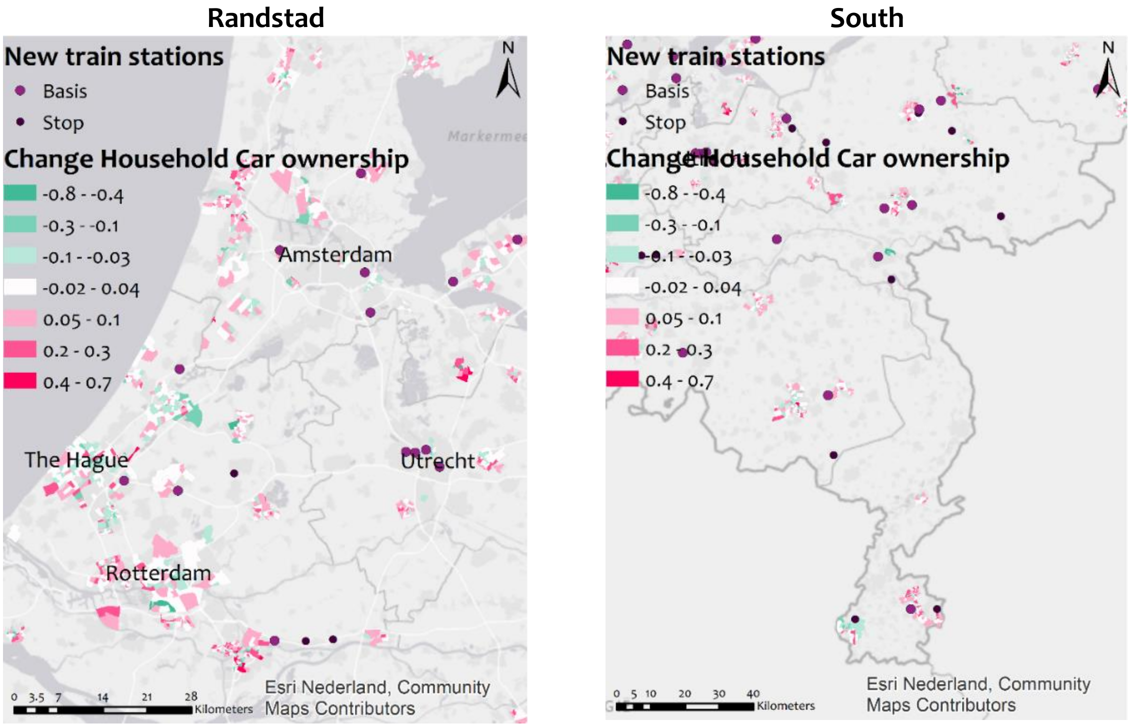


Figure 6-5 Changes in household car ownership between 2005 and 2015 and the new train stations that have opened in that period of time

Figure 6-5 shows the explanation for this relatively low number of *buurten*. The new train stations have not been built in the inner cities but in the suburbs of the cities. The selection criteria were again at least moderately urbanised areas in at least very urbanised municipalities. Therefore, this results in a selection of the inner cities and the surrounding *buurten* with hardly any suburbs. So, not many *buurten* in the data selection are located near the new train stations. On top of that, changes in the geometrics and names of *buurten* in, for example, Amsterdam and Utrecht make it impossible to compare the differences over time. Visually, the direction of change in average household car ownership seems not influenced by the new train stations.

Figure 6-7 (left) shows the residuals for household car ownership for neighbourhoods at a timestep in the number of years before and after the opening of a train station. The train stations are opened in the years between 2005 and 2017. For example, if a train station is opened in 2017, then household car ownership is known twelve years before the opening of the train station until zero years before the opening. If a train station is opened in 2010, then household car ownership is known from five years before the opening until seven years after the opening. So, at each time step are the residuals of different train stations at the same number of years before or after the opening of a train station shown.

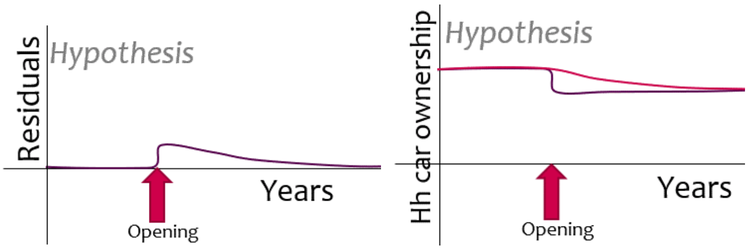


Figure 6-6 Left: hypothesised residuals before and after the opening of a train station. Right: hypothesised expected household car ownership (purple) and actual car ownership (pink)

The hypothesis was that households would not directly adapt their car ownership to the new situation in the built environment: the residuals should, therefore, increase at the opening of a new train station (household car ownership become higher than expected) and slowly decrease to zero. This hypothesis is visualised in Figure 6-6.

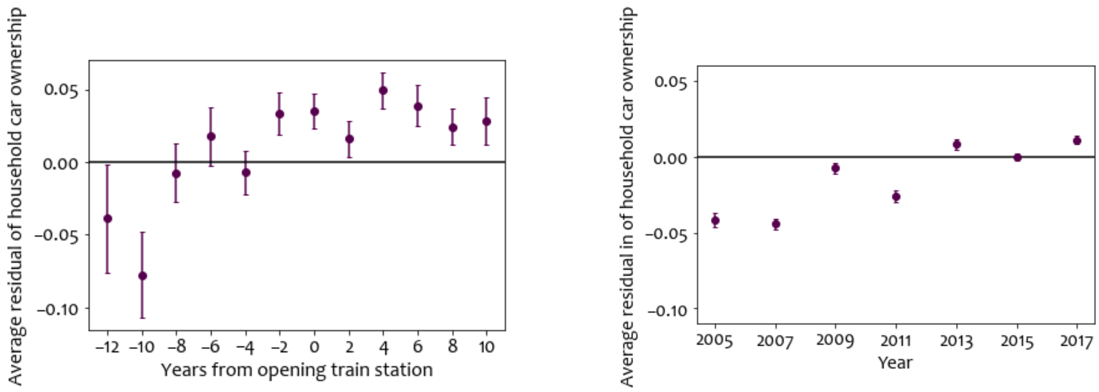


Figure 6-7 Expected and actual household car ownership. Left: data of neighbourhoods with the changed nearest train station at year zero. Right: the whole dataset.

The residuals are determined by the difference between actual household car ownership and the results of the linear regression model of Chapter 5 (model C). Nonetheless, the residuals after the opening of the station are not decreasing to zero. This can be explained by the right graph in Figure 6-7, the predictions in the earlier years are systematically lower than expected. This might be caused by trends in actual household car ownership and the changes in parking permits. Therefore, the differences cannot be clearly interpreted in the left plot of Figure 6-7. On top of that, from Chapter 5 followed that the impact of Basis and Stop stations was nihil to no effect. To overcome the incomparability, a multiple linear regression model is applied over a longer time with as dependent variable the difference in household car ownership in the next section.

6.5 Multiple Linear Regression models

On average, household car ownership has increased in the years 2005-2015 as followed from the previous sections. Figure 6-8 confirms this observation with a histogram of the changes in average household car ownership, with a larger frequency for the positive values. Average household car ownership seems relatively stable; about 95% of the neighbourhoods in the selection have changes between ±0.2 cars per household in household car ownership. To explain these changes multiple MLR models are constructed. Nonetheless, data of parking permits are only available for 2019 and are only neighbourhoods in the selection that do not have a parking permit requirement in 2019. From the descriptive statistics followed that the percentage of people with age between 25-45 is strongly negatively correlated with the age group 45-65. Therefore, the variables are not analysed in the same model.

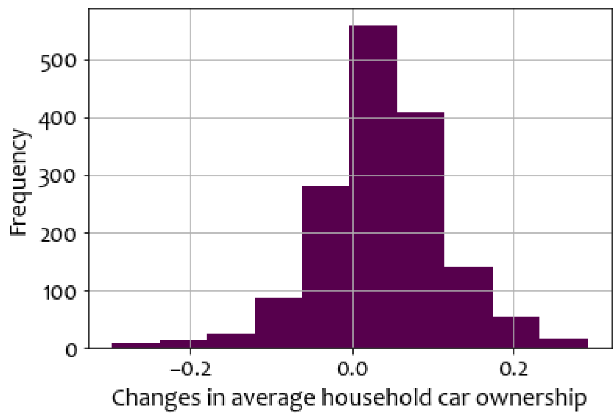


Figure 6-8 Histogram of changes in household car ownership between 2005 and 2015

The arrival of train stations has not a significant effect on the changes in household car ownership in the three MLR models in Table 6-2. There are multiple reasons for this result. At first, there is only a very small number of neighbourhoods with changes in nearest train station, and second the new train station types basis and stop have relatively low to hardly any impact on average household car ownership in the models of Chapter 5. Different from Chapter 5 is now minimum distance and presence of larger train station type not added into the models: the reason is that changes in larger train station and minimum distance automatically affect the nearest train station. This leads to a high correlation among the independent public transport variables. The models with the variable changes in largest train station type instead of nearest train station type have similar results as Table 6-2 and are therefore not shown.

Table 6-2 Multiple linear regression model for change in average car ownership between 2005 and 2015

Dependent variable: **Change in average household car ownership**	**Multiple Linear Regression model**		Difference between 2015 and 2005 (N = 1629)	
	Model A		Model B	
Variable	Coef.	Beta	Coef.	Beta
Constant	0.0607**	0.0383**	0.0579**	0.0392**
Built environment				
Urbanisation level Municipality (ref. = 1)				
2. Level 2	-0.0016	-0.0016	-0.0026	-0.0026
Public transport				
Change in nearest train station type (ref = no change)				
1. New train station Basis	-0.0017	-0.0017	-0.0079	-0.0079
2. New train station Stop	0.0085	0.0085	0.0137	0.0137
Socio-demographics				
Percentage of lowest 40% income	-0.0025**	-0.0364**	-0.0024**	-0.0338**
Average household size	0.2368**	0.0381**	0.24**	0.0386**
Percentage of age 25-44	-0.0008	-0.0042		
Percentage of age 45-64			0.0029**	0.0165**
	R^2	0.244	R^2	0.266
	σ_{est}	0.090	σ_{est}	0.088

All coefficients and betas are insignificant at 95% confidence interval (p>0.05) except of the values with:
*** Significant at 95% confidence interval (p<0.05)**
**** Significant at 99.9% confidence interval (p<0.001)**

The directions of the effect of the socio-demographic variables are similar to Chapter 5. Nonetheless, the proportions of standardised parameters have changed, see Table 6-2. Where in Chapter 5 the percentage of lowest income has the largest effect on average household car ownership, seems now the household size just as important. A possible explanation may be that changes in household sizes are more disruptive life events and changes in income may be more gradual and do not directly lead to a decision to change household car ownership. Furthermore has a change in percentage of people between 45-65 a significant positive effect as expected, but the age group 25-45 does not have a significant negative effect which is not in agreement with Chapter 5.

In agreement with the earlier observations is the constant positive. This means that even without any changes in the independent variables, average household car ownership slightly increases over time. However, the low value of R-squared indicates that there are still changes in car ownership that cannot be explained by changes in the variables. These changes may be a result of random error or are influenced by factors that were not included in the models.

6.6 Conclusion

This chapter aimed to find out whether new train stations influence a change in average household car ownership. Nonetheless, there is no significant effect of train stations found. Because the new train station types were the types with hardly any to no effect in Chapter 5, this chapter does not show that there is no causal relationship between proximity to train stations and average household car ownership at all. Only can be concluded that in neighbourhoods with new small train station types the residents will not change their household car ownership directly.

Only changes in socio-demographics have a significant relation with the change in average household car ownership. Although this study focuses on the new train stations, the findings may have a bearing on the parking policy. Especially the targeted audience for the residences may affect the corresponding average household car ownership. Furthermore, it would be recommended to analyse whether the parking permits have been introduced in the investigated time to clarify the change of the coefficients.

Q2	*What is the effect of new train stations on average household car ownership in urbanised areas?*

In an aggregated study to changes in neighbourhood characteristics in time are the influencing factors for changes in average household car ownership analysed. Although there are significant effects of the socio-demographics in line with the previous results, the changes of additions of train stations did not have a significant effect on average household car ownership. Nevertheless, only the two train station types with the lowest number of passengers (Basis and Stop) opened in the investigated time in just a small selection of neighbourhoods. Therefore, there can only be concluded that the addition of the train stations with the lowest amount of passengers did not significantly affect average household car ownership of the neighbourhoods in the dataset.

7 Disaggregated analysis

This section of the report contains the results of the analysis with the panel data of Netherlands Mobility Panel (MPN). The first sections are about the influence of preferences on household car ownership and the second part is about the effect of relocation train station areas as a result of household relocating.

7.1 Data description

The MPN contains annual data of households' characteristics, mobility patterns, preferences, life events etcetera. Currently, the first four waves (2013-2016) are available by KiM, Netherlands Institute for Transport Policy Analysis. Only households are selected in the sample if all the household members completed the survey and if enriched data was available. Furthermore, only households in urbanised areas are in the selection. A complete household is necessary for the determination of the relocation of the households: the survey only contains variables whether the respondent has moved and not if the whole household has moved. So, if only one member of the household reported having moved, then only this household member may have left the household and has the household size changed. The MPN contains respondents of about 2500 complete households and after the data preparation are still 1379 complete households left in the sample, see Table 7-1.

Table 7-1 Data description disaggregated data

Data	Characteristic	The Netherlands in 2014	Sample 2013-2016
Households	Number of occurrences	7.59 million	1379
Residents	Number of occurrences	16.83 million	2926

7.2 Household car ownership and train stations

Household car ownership of the sample of 2014 is analysed to find out whether the same relations as in Chapter 5 hold between household car ownership and (proximity to) train stations. The year 2014 is chosen because only the even years contain questions about living preferences and the year 2016 did not contain information about income and ages.

For the households in the selection are the relations with proximity to train stations investigated to find out whether the results in the previous chapters are applicable on household-level (instead of neighbourhood level) too. Figure 7-1 shows that for this sample holds that the longer the distance to the train station, the higher the household car ownership. The latter is in agreement with Chapter 5. Especially the households near intercity train stations have approximately the first 3km to the train stations lower household car ownership than the households near any train station. At longer distances there seems no clear difference in household car ownership between those neighbourhoods, which is in agreement with Chapter 5 too.

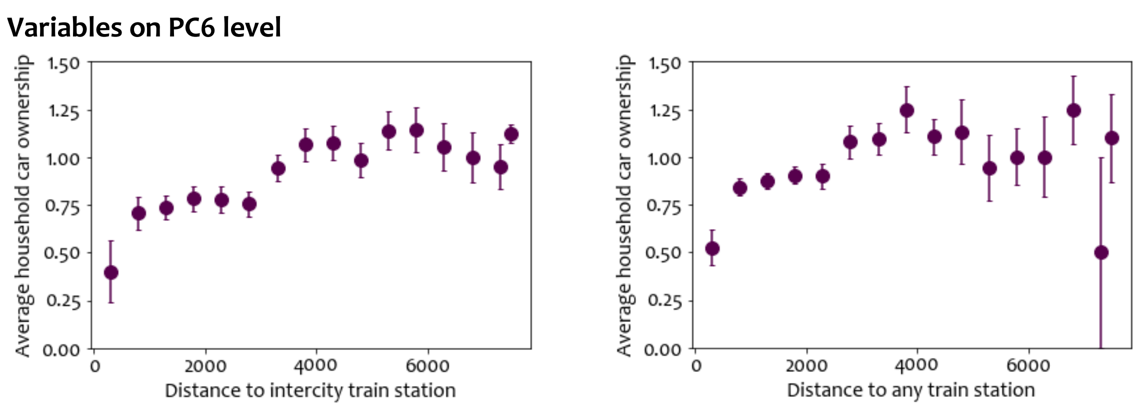


Figure 7-1 Averages of household car ownership in relation to (proximity to) train stations with households locations on PC6 level

Variables on *buurt* level

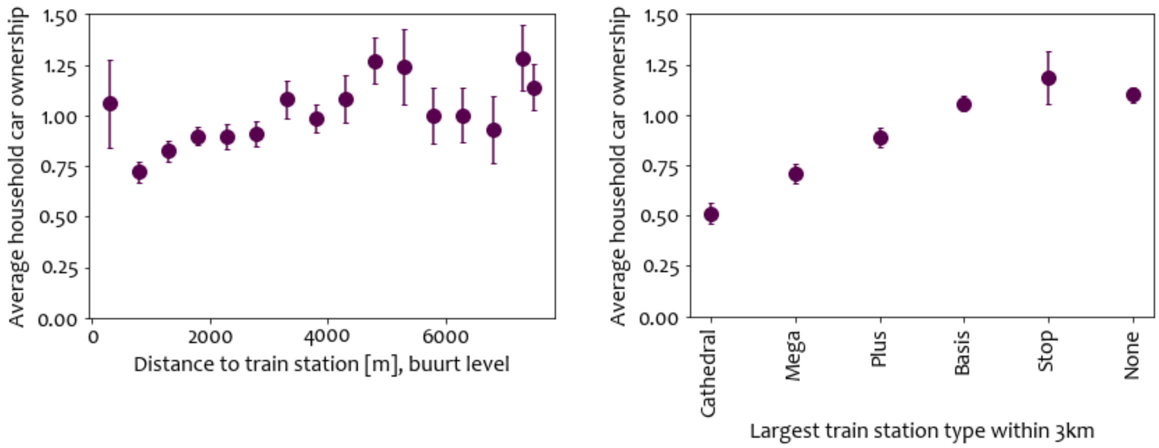


Figure 7-2 Averages of household car ownership in relation to (proximity to) train stations with household locations on buurt level.

Figure 7-2 uses distances to the train stations again, nonetheless now is data on *buurt* level used. The left graph of Figure 7-2 should have comparable results as the right graph of Figure 7-1, since they represent the same variable. The results are comparable with only one large difference: the first bin of the households nearer than 300 meters. The size of the spatial level can explain this difference. Since PC6 areas are smaller than *buurten*, the actual distances of the houses should be more accurate than on *buurt* level. On top of that, the probability of very small distances with data on *buurt* level is lower because the distance to the centre of a *buurt* is larger than on PC6 level.

The relations on household car ownership are comparable with the results of Chapter 5. Only the requirement of parking permits did not have a significant effect on household car ownership while controlling for other variables, whereas paid parking has a significant effect on household car ownership. A possible explanation may be that the requirements of permit are self-reported by the residents. So, residents without cars are more aware of paid parking than parking permits in their residential area. So, in general, the relations in the MPN dataset are comparable with the results of Chapter 5.

7.3 Dissonance and consonance

This section focusses on the (mis-)match of travel preferences and residential location. The special interest goes to the difference in car ownership between dissonant and consonant households in train station areas. As a recap from Chapter 2.3: dissonant households are households do not have a matching residential location with their travel preferences and needs, while consonant residents have a matching residential location. The same *buurt* data of Chapter 5 with largest train station type within 3km average bike distance is used to define whether people live in train station areas of the five train station types. The residential preferences are retrieved from the MPN question whether the choice for current living situation is influenced by the presence of a train station.

7.3.1 Determination of treatment groups

From the literature study followed that there are several methods for the determination of consonant and dissonant residents. In this case, the main interest is train station areas and therefore the focus is on the train presence and preference. The preference for a train station in proximity is measured by the following MPN proposition: "*The presence of a train station within walking or cycling distance was an important factor in my choice to reside at my current address*". The presence of the train station is measured by the largest train station type within 3km biking distance of the *buurt*. The two variables that are used for the determination (Figure 7-3 shows the histograms) show that there are households with no specific preference or are not located at a typical train-rich or train-poor neighbourhood. Those respondents will not fit in the dichotomous box of being consonant or not.

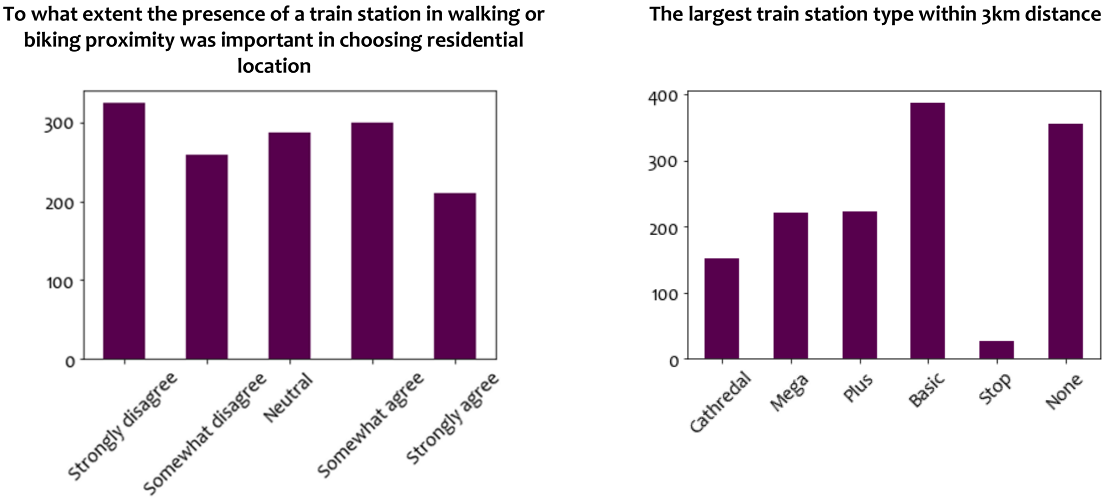


Figure 7-3 Histograms for the two factors of the definition of dissonance and consonance for gatekeepers for year 2014 (N=1379)

Therefore is decided to follow the method of (Wolday et al., 2018) with a 3x3 cross-tabulation see Table 7-3. In that case, the classifications of the boxes are based on the standard deviation and the mean: the values in the interval mean plus or minus the standard deviation are handled as mediocre or medium and are out of the scope.

The four types in the scope are: Train-rich consonant (TRC), Train-rich dissonant (TRD), Train-poor dissonant (TPD) and Train-poor consonant (TPC). For example, a train rich consonant household lives in an area with a large train station in proximity and that household took the preference to the presence of a train station into account in the residential location choice of their current dwelling. A train-poor consonant lives in an area without a large train station type in proximity and states that the train station was not an important factor in location choice.

There is assumed that the residential location choice is a household decision and that therefore, the answers of the gatekeeper about the residential preference are representative for the household. The gatekeeper is the person who maintains the contact with the research bureau and answers the general questions about the households (like for example the postal code, number of household members etc.).

The applied boundaries for residential preferences, residential locations and number of households per group are shown in Table 7-2. About 43% of the households are part of the Medium and mediocre groups and therefore not in the sample.

Table 7-2 Treatment groups and frequencies (for 2014)

	Largest train station	Residential preference of gatekeeper for train station by choice of current location	Count
Train rich consonant (TRC)	Cathedral, Mega, Plus	Somewhat agree & Strongly agree	195 (14%)
Train rich dissonant (TRD)	Cathedral, Mega, Plus	Somewhat disagree & Strongly disagree	291 (21%)
Train poor dissonant (TPD)	Stop, None	Somewhat agree & Strongly agree	226 (16%)
Train poor consonant (TPC)	Stop, None	Somewhat disagree & Strongly disagree	77 (6%)
Not in sample			595 (43%)

Table 7-3 Determination of consonance and dissonance (Wolday et al., 2018)

Preference for train station in residential area	**Access to train stations** Rich	Mediocre	Poor
High	Train rich consonant (TRC) 	-	Train poor dissonant (TPD) 
Medium	-	-	-
Low	Train rich dissonant (TRD) 	-	Train poor consonant (TPC) 

7.3.2 Comparison of household car ownership

Household ownership is compared for the four treatment groups. The results of this comparison are shown in Table 7-4.The differences in car ownership of the households in the four treatment groups are compared with one-way ANOVA with post hoc Turkey's HSD tests. The differences between the train rich and train poor areas are in agreement with Chapter 5: car ownership is lower in train rich areas. Nonetheless, the results show differences between the consonant and dissonant groups in the same residential area too. Consonant households with a large train station in proximity have on average significantly lower car ownership than the dissonant households. The same counts for train-poor areas: the households that did not find train stations important in residential location choice have on average higher car ownership than households that did find it important. Strikingly, there is no significant difference in household car ownership between train rich dissonant and train poor dissonant households.

Table 7-4 Mean (differences) in household and personal car ownership for the different treatment groups

	Household car ownership Mean	Std error
Train rich consonant (TRC)	0.56	0.04
Train rich dissonant (TRD)	0.89	0.05
Train poor dissonant (TPD)	0.83	0.10
Train poor consonant (TPC)	1.19	0.05
	Mean difference	
Difference TRC – TRD	0.32**	
Difference TRC – TPD	0.27*	
Difference TRC – TPC	0.63**	
Difference TRD – TPD	-0.06	
Difference TRD – TPC	0.31**	
Difference TPD – TPC	0.36**	

* Significant at 95% significance level for Tukey's HSD
** Significant at 99% significance level for Tukey's HSD

7.3.3 Comparison of travel behaviour

The difference in the travel behaviour of the gatekeepers of the households in the four treatment groups is compared with one-way ANOVA with post hoc Turkey's HSD tests. In agreement with literature are train-rich consonant households commuting significantly more frequently by train than households in other treatment groups. For the other transport modes are no significant differences between the households with preference for the presence of train station in the residential location. So, not only train use is higher among residents that prefer to live near a train station, but the use of bikes and other public transport modes too. Consequently, in the groups that did not prefer to live near a train station is car use higher.

Table 7-5 Mean (differences) in frequencies of use for the different treatment groups

	Frequency Car			Frequency Train			Frequency Bike			Frequency Bus, Tram, Metro		
	Mean	Median	Std error	Mean	Median	Std error	Mean	Median	Std error	Mean	Median	Std error
TRC	2.05	1	0.11	2.86	3	0.11	1.57	1	0.09	2.93	3	0.11
TRD	1.54	1	0.13	4.21	5	0.12	1.94	1	0.15	3.67	4	0.15
TPD	1.83	1	0.22	3.62	4	0.24	1.53	1	0.22	3.08	3	0.25
TPC	1.00	1	0.07	4.91	5	0.09	2.05	1	0.13	4.09	5	0.13
	Mean difference			*Mean difference*			*Mean difference*			*Mean difference*		
TRC - TRD	-0.51**			1.35***			0.37			0.74***		
TRC - TPD	-0.22			0.77**			-0.04			0.14		
TRC - TPC	-1.05***			2.06***			0.48*			1.16***		
TRD - TPD	0.29			-0.58			-0.41			-0.59		
TRD - TPC	-0.54**			0.71***			0.11			0.42		
TPD - TPC	-0.84**			1.29***			0.52			1.02***		

* Significant at 95% significance level for Tukey's HSD
** Significant at 99% significance level for Tukey's HSD
** Significant at 99.9% significance level for Tukey's HSD

With frequency:
1 = 4 or more days per week
2 = 1 to 3 days per week
3 = 1 to 3 days per month
4 = 6 to 11 days per month
5 = 1 to 5 days per year
6 = less than 1 day per year

7.3.4 Residents

Among the four different treatment groups vary household car ownership and travel behaviour. In policymaking and development of housing, it would be convenient to know which household types would be dissonant and consonant. Attracting only consonant households in train station areas would be beneficial for train usage and more liveable low car ownership areas. The consonant and dissonant treatment group in train rich area differ only significantly at a 95% confidence interval in income, origin and average household car ownership in the neighbourhoods see Table 7-6. There are more lower incomes among consonant residents, more native Dutch and lower average household car ownership in the neighbourhood.

Table 7-6 Description of treatment groups in train rich areas in 2014

Variable	Category	Consonant	Dissonant	P-value chi-square	P-value t-test
Income	1. Minimum (<12,500)	16%	8%	0.19	
	2. Below the national benchmark income (12,500-<26,200)	19%	20%		
	3. National benchmark income (26,200-<38,800)	20%	23%		
	4. 1-2x the national benchmark income (38,800-<65,000)	24%	22%		
	5. 2x the national benchmark income (65,000-<77,500)	3%	4%		
	6. More than 2x the national benchmark income (>=77,500)	8%	8%		
	7. Unknown	11%	15%		
Education level	1. No education	0%	1%	0.00	
	2. Primary education	1%	4%		
	3. LBO \ VBO \ VMBO (vocational educational programs)	4%	10%		
	4. MAVO\1st 3 years HAVO-VWO\VMBO (junior years high school education)	5%	11%		
	5. MBO	15%	21%		
	6. HAVO and VWO senior high school year(s) \ university propaedeutic diploma	14%	15%		
	7. HBO\WO (Bachelor's degree)	33%	25%		
	8. University Master's or doctoral degree	26%	14%		
	1. Single person household	60%	47%	0.00	

Variable	Category		Consonant	Dissonant	P-value chi-square	P-value t-test
Household composition	2.	Couple	23%	19%		
	3.	Couple + child(ren)	12%	21%		
	4.	Couple + child(ren) + other(s)	0%	1%		
	5.	Single parent family + child(ren)	4%	11%		
	6.	Single parent family + child(ren) + other(s)	0%	1%		
	7.	A different type of family situation	0%	0%		
Age		Age	43	46		0.04
Origin	1.	Native Dutch ethnic origin	90%	84%	0.11	
	2.	Western ethnic origin	7%	10%		
	3.	Non-Western ethnic origin	2%	6%		
	4.	Unknown	1%	1%		
Buurt:		Household car ownership	0.7	1.1		0.83
		Perc. Lowest 40% income	52	51		0.00
		Average household size	2	2		0.00
		Percentage of residents with age 25-44	33	31		0.00
		Percentage of residents with age 45-64	24	25		0.00
Urb. Level munic.		Extremely urbanised municipality	57%	42%		0.00
		Strongly urbanised municipality	43%	58%		

Household car ownership of the different treatment groups is compared with the expected average household car ownership in the neighbourhoods based on the MLR results, see Figure 7-4. There is a significant difference at a 95% confidence interval between the group (Chi-square test), except for the difference between TRC and TPD. It seems that people with a preference for train stations have on average less frequently higher car ownership than the expected car ownership in the neighbourhood. So, this indicated that even by taking into account the *buurt* characteristics, the preferences might still have a role in average household car ownership.

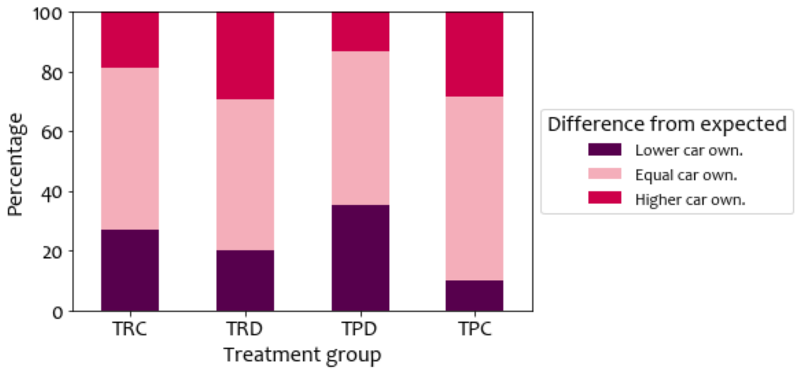


Figure 7-4 Frequencies of households with lower, equal or higher household car ownership than expected in their neighbourhood

7.3.5 Concluding

There is a significant difference in household car ownership between dissonant and consonant residents in train station areas. The socio-demographics of the groups can partly explain this. On top of that, there is a significant difference in household car ownership between the train station rich consonant and train station poor dissonant households. Household car ownership is lower and train use is higher of the train station rich consonants than the other four groups. Therefrom can be concluded that both travel preference and built environment affect household car ownership. Nonetheless, further research is required to the composition of the groups and influencing factors of dissonance.

7.4 Relocations

The relocators in the dataset are analysed to find out whether people change their car ownership when they move to train station areas. In the dataset are not many households that reported to have moved in the analysed waves. Both the change in car ownership before and after the move is analysed to make sure that both the preparation as the result of the move are included. Therefore, only the movers in the years 2014 and 2015 are point of interest. In total 103 households moved in the years 2014 and 2015.

Figure 7-5 visualises the changes in car ownership over time. Timestep t represents the household car ownership in the year of the reported move, 2014 or 2015. Timestep t-1 represents the reported number of household cars in the year before the move, t+1 represents the number of cars the year after the move. Gross of the movers (85%) in Figure 7-5 did not change their car ownership before and after the move. Only about eight per cent of the movers acquires a car, and about the same percentage of households disposes a car. Most of the exchanges in car ownership occur between household car ownership of zero and one. It is striking that more carless households acquired a car before the move than after the move and that single car-owning households disposed of their car after the move than before. The following sections will try to find explanations for the changes in car ownership.

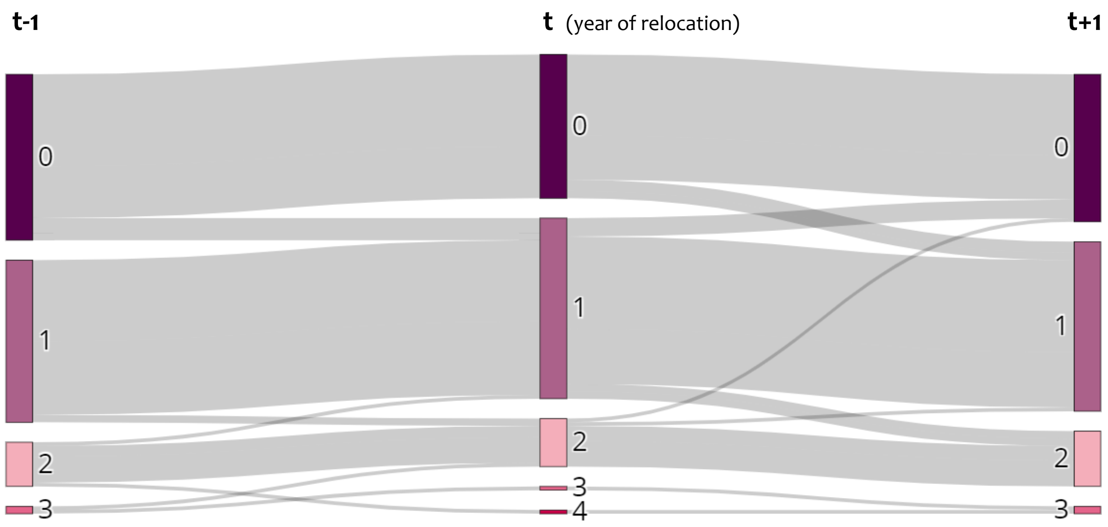


Figure 7-5 Sankey diagram: Changes in household car ownership when households relocate at year t (N=103)

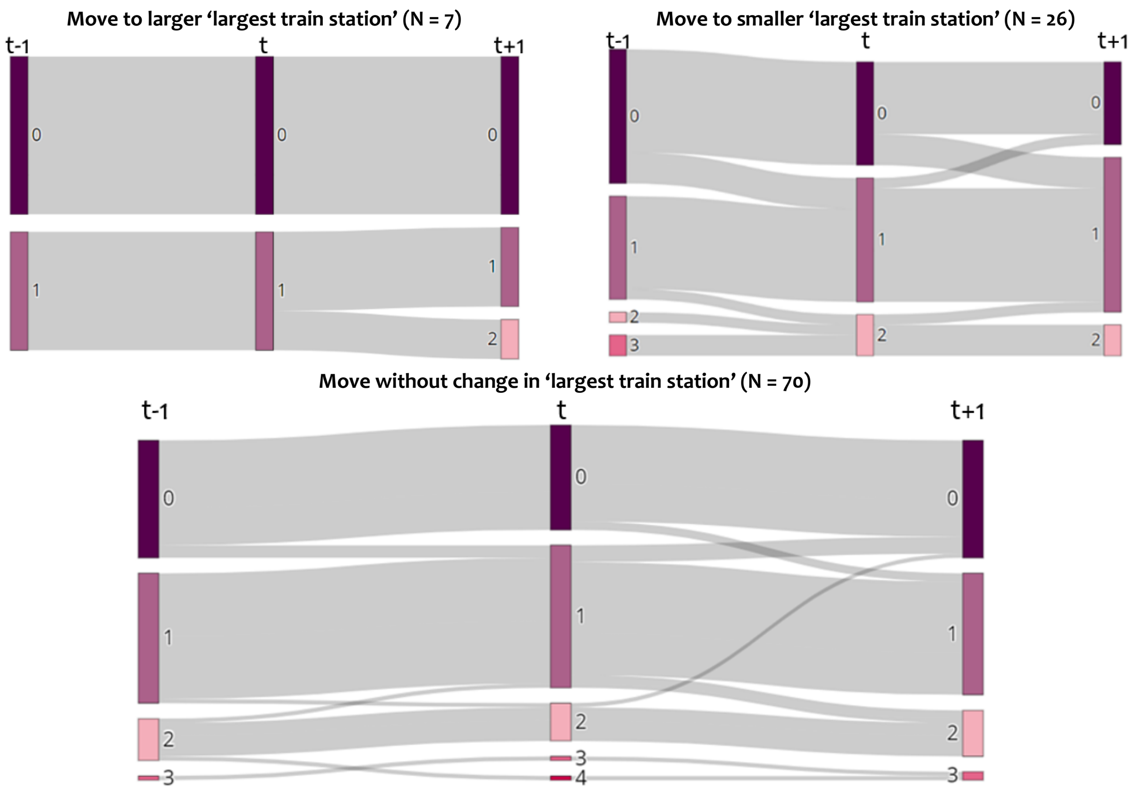
7.4.1 Train stations areas

There are hardly any movers to areas with larger train stations than before: only seven households moved to a larger largest train station type within 3km. Because the number of these movers is very low and the number of people with changes in train station types is even lower, the analysis won't lead to significant results. However, it is still possible to analyse the effects of moving can qualitatively. The hypothesis was that households moving to larger train stations would have a larger probability to dispose their car. Table 7-7 does not show a confirmation of this hypotheses. Contrary to the expectations, there are hardly any changes among the movers to larger train stations.

Nonetheless, among the movers to smaller train stations are car acquirements before and after the move. It is striking that the number of households with zero car ownership households decreased and the number of households with one car has increased after the move. Although there are some changes in average household car ownership among the movers at locations without a change in train station, the proportions in number of cars per household remain constant.

Only half of the households that reported that they have become in possession of a new mode of transport in the period around their relocation reported that the move itself was one of the influencing factors. Possibly, the relocations themselves may not have been the decisive factor in the choice for the acquirement of the car but the locations may supply the possibility for the acquiring of the car.

Table 7-7 Changes in household car ownership when households move at year t to larger train stations, smaller train stations or no change in largest train station type in the neighbourhood



7.4.2 Conclusion

In the researched waves of the MPN-dataset is the number of relocations low. The goal was to find out whether train stations have a causal effect on household car ownership. The overview of the relocators showed more acquired cars before the move and more disposed cars after the move. Especially, car ownership has changed among the movers to the smaller train station types. While before the move the largest proportion of households had zero cars, had the largest proportion of households one car after the move. So, the changes in household car ownership seem related to relocating to areas with smaller train stations in proximity. However, due to the small sample was not possible to control for possible other influencing factors. Therefore, a repetition of this study after more waves of MPN is available would be beneficial to gain more statistical power.

7.5 Conclusion

This chapter aimed to find out more about the causality of the relation between train stations and household car ownership. The study to preferences to live in train station areas and the actual living locations showed that both built environment and the preferences had a significant effect on household car ownership. This also holds for travel behaviour. Nonetheless, further research is required to this effect while controlling for socio-demographics. The influence of preferences and built environment is an important factor for policymaking, this shows that in new development car ownership can be influenced by both the residential location and attracting target groups with a corresponding travel preference.

The study to relocations showed that, although the number of relocators was low, households change their car ownership before and after the move. Especially, car ownership has changed among the movers to the smaller train station types. While before the move the largest proportion of households had zero cars, had the largest proportion of households one car after the move. The results point out that train stations may have a causal relation with household car ownership. Nonetheless more data is required to provide more foundation for these results.

Q3 *How does household car ownership and travel behaviour differ between consonant and dissonant residents in areas with and without train stations in proximity?*

In a cross-section study of the year 2014 of the Netherlands Mobility Panel, the analysis contains a comparison of household car ownership of dissonant and consonant residents. In line with previous research, are both the preference to live in a train station area and the presence of the train station areas of influence on the frequency of train use of the gatekeeper. Even more important, there is a significant difference in household car ownership between dissonant and consonant residents in train station rich areas. Nevertheless, there are some small differences in socio-demographics of the groups, which may have a (partial) explanation for the difference in household car ownership of the groups. Furthermore, there is a significant difference in household car ownership between the train station rich consonant and train station poor dissonant residents. So, both travel preference and built environment affect household car ownership.

Q4 *How does household car ownership change when people move to locations with different train station proximity than before?*

Changes in household car ownership of movers in the years 2014 and 2015 of the Netherlands Mobility Panel are analysed to find out whether train station areas have a decisive effect in acquiring or disposing of cars. The number of relocators in the sample is low, therefore is it not possible to have conclusions with a statistical significance. Nonetheless, the households have increasing household car ownership when the relocators move to areas with train stations with a lower number of passengers. These results indicate an effect of the built environment, but the characteristics and the reasons people have moved should be further analysed to conclude about the causality. Therefore, additional data should be acquired to get more insights into the choices in household car ownership.

8 Parking standards

This chapter contains the analyses of parking standards of municipalities. The results of this analysis are used to highlight where parking standards can be approved. At first, a description follows of the brief analysis of the residential parking policies of municipalities. Next, a comparison follows of the CROW Key figures, the municipalities' parking standards and the results of Chapter 5 with actual average household car ownership.

8.1 A brief analysis of municipalities' parking standards

Since 1 July 2018, municipalities have been forced to accommodate parking standards in their zonal plans. Gross of the municipalities refers in the zonal plans to a municipal umbrella parking vision plan with the applicable parking standards. This strategy makes it possible to adjust the parking standards without making adjustments to the Zonal Plans. Therefore, this brief analysis makes use of the umbrella plans and parking vision documents of the municipalities.

As a background, the literature study contains a description and analysis of the CROW Key figures plus a description of experts opinions (Chapter 2.4). As followed by the literature study, the CROW key figures are the foundation of many municipal parking standards. A brief analysis of the extreme and very urbanised municipalities residential parking standards policy documents confirms this statement. The municipalities use comparable methods for the implementation: the reports contain the minimum required number of parking places per urban zone, and building type.

Nonetheless, there is a large variation among the municipalities in the applied number of the building types and definition of the zones. The Key figures of 2012 and 2018 contain fourteen residential building types with variation in price, ownership (rental, private) and type (e.g. terraced, apartment etc.), but earlier editions only varied in price, service flats and rooms (five groups). In practice, use the municipalities parking standards for three to fourteen house types. Where some municipalities claim that they only present the parking standards for building types that are common in their region, claim others that they simplified the parking standards for practicability.

The zones in the urban areas (centre, shell, built-up area and rest) are mostly based on the city centre of the municipality and its surrounding neighbourhoods. Some municipalities define the area near a train station as centre or shell too. Nonetheless, there are municipalities with multiple city centres. Those centres can be shopping areas of larger districts or centres of the villages or cities in the municipality. For these polycentric municipalities, the choice for the urbanisation level differs. There are even municipalities that change the urban level per zone. Three examples of the differences in zones are shown in screenshots of the policies in Figure 8-1, Figure 8-2 and Figure 8-3. In the CROW key figures of 2004 use urbanisation level of municipalities to differentiate between municipalities or cities. Therefore, the application of multiple urbanisation levels in a monocentric municipality seems double.

Most of the municipalities only present the minimum number of required parking places. Mostly, this number is a choice in the bandwidth of the Key figures, see the example in Chapter 2.4.3. Based on the characteristics of the area, or urbanisation level of the municipality are the numbers determined. Some municipalities base their parking standards on actual car ownership, while some use actual car ownership and even one municipality uses the parking pressure for the position in the bandwidth. Nonetheless, many municipalities estimate whether they have to use the minimum ór the average of the CROW Key figures bandwidths. Furthermore, a small selection of municipalities uses bandwidths to define the minimum required and maximum allowed number of parking places. Finally, there is a small selection of municipalities that refer to the CROW Key figures as their parking standards. Where a few indicated their choices in the urbanisation level and the urban zone.

How strictly the parking standards are applied for new development location is not known from this analysis. From the expert interviews (see Chapter 2.4.4) followed that some municipalities use their parking standards as an absolute minimum. This means that new developments will not get a license to build if the plan to build less parking places than the required minimum. In a few policy documents is explicitly mentioned that the required number of parking places needs customisation and that with a reasonable foundation can be a deviated from the parking standards.

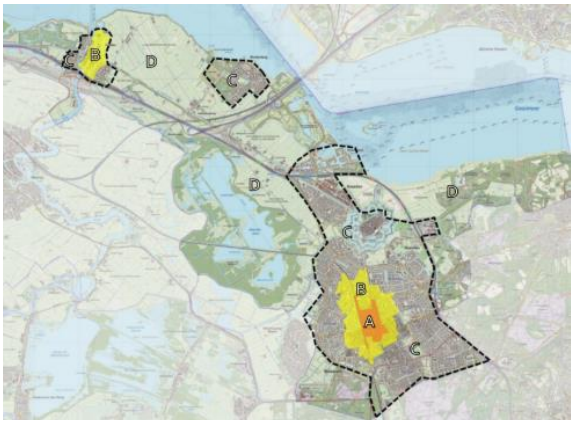


Figure 8-1 Polycentric municipality: Gooise Meren (Municipality Gooise Meren, 2019)

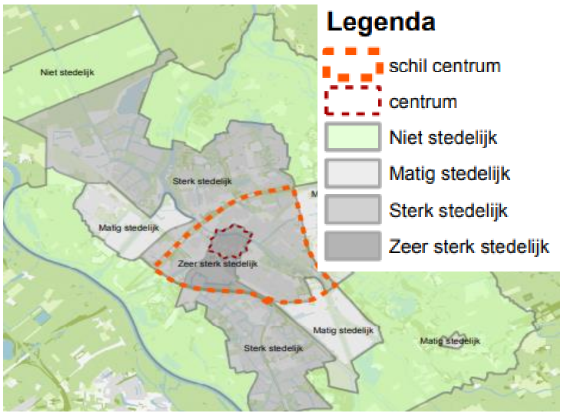


Figure 8-2 City with multiple urbanisation levels and zones: Zwolle (Municipality Zwolle, 2016)

Figure 8-3 More common zonal classification: Eindhoven (Municipality Eindhoven, 2016)

So, most of the municipalities make use of similar structures to display and organise the parking standards. However, the application and extent of use of the CROW Key figures differ among the municipalities.

8.2 Case studies

From the literature analysis followed that especially the parking standards for rent apartments were very high in comparison to actual household car ownership. The largest extent of municipalities overestimated the required number of parking places with at least +200% percentage deviation (BPD, 2018). Contrary, private houses and apartments had smaller deviations than the rental apartments in terms of percentage. So, the overestimations were to the largest extent attributed to the low variation in the parking standards. The analysis of the parking standards confirms this low deviation in housing types. However, the percentage of deviation may indicate biased results because rental apartments already have lower car ownership. So, the same absolute deviation would have a larger relative deviation.

On top of that, the role of train stations in this deviation is unknown. Therefore, this chapter analyses two case studies: rent apartments and private terraced houses.

Neighbourhoods were selected by their urbanisation level, urban zone and house type. Nonetheless, there is no open-source dataset available with house types per neighbourhood. Therefore, the house types are an estimation with the percentage of rent houses, percentage of multi-family houses (e.g. apartment), house values from CBS, floor area of Kadaster and satellite photos of Google Maps. The parking policy documents of the municipalities are used for the estimation of the current parking standards of the municipality. If relevant, the parking standards needed a reduction with the share of visitors. In general, this reduction is 0.3 cars per household. The CROW key figures date from 2018, and the minima, maxima and the mean of the bandwidth were based on the urbanisation level of the municipality and urban zone. Again, only the share of the residents represents the key figures. Finally, the results from Chapter 5 of model D are used to compare the results of the model with the current policy.

8.2.1 Case study 1: Average rental apartments

The following characteristics of the neighbourhood selected the rent apartments: more than eighty per cent of rent buildings, more than 85 per cent multi-family dwellings and a percentage of household with the lowest 40% of income between 65 and 75. The latter was needed to only select the most general type of rent apartments: the middle to cheaper priced apartments. Satelite photos and Kadaster maps of the residents validated that this selection includes to the largest extent rental apartments.

In this section are the parking standards of the rental neighbourhoods compared with actual car ownership given the proximity of the largest train station types. In Table 8-1 is the average household car ownership of the neighbourhoods shown, where only not any neighbourhood in the selection had a Stop train station as largest train station type. Car ownership is on average the lowest at the Cathedral and the highest at neighbourhoods with no train station within 3km, which is in agreement with Chapter 5.

Table 8-1 Descriptive statistics of average household car ownership of the neighbourhoods

	Cathedral	Mega	Plus	Basis	Stop	None
Mean	0.33	0.4	0.45	0.56		0.57
Min	0.2	0.16	0.3	0.42		0.41
Max	0.47	0.61	0.6	0.7		0.67
Count	10	13	9	15	0	10

Model D has small residuals for the neighbourhoods, wherefrom can be concluded that the neighbourhoods are predictable or are no outliers, see Figure 8-4. The current parking standards of the municipalities with a Cathedral or Mega train station seem accurate. There are only a few underestimations, see Figure 8-5. Although, those underestimations can be explained by the policy of the municipality of Amsterdam. The current policy is a minimum of zero in the inner city, which automatically results in an underestimation of actual household car ownership. The main reason of this policy is the lack of public space and the goal to develop more residences while keeping the city accessible by foot, bike, public transport and cars (Gemeente Amsterdam, 2017).

The estimated minimum parking standards of the municipality are on average significantly higher than actual average household car ownership for the train stations Plus and Basis and no train station, see Figure 8-4. The municipalities chose for parking standards more close to the average bandwidth or even the maximum of the key figures.

An explanation for these overestimations may be the choice of municipalities to simplify the parking standards. About half of the municipalities at Basis, Plus and None train station types did not use different parking standards for apartments than for ground-level residences and about a quarter used different parking standards for rent residences than for private residences.

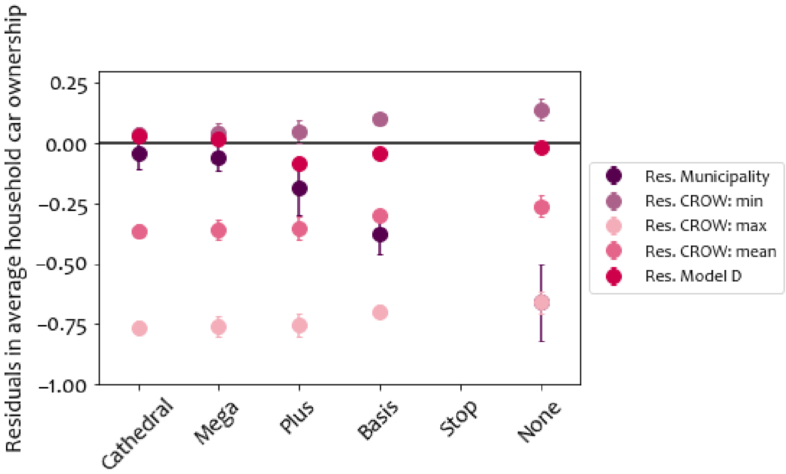


Figure 8-4 Comparison of residuals for rent apartments with CROW, municipal policy and Model D of Chapter 5

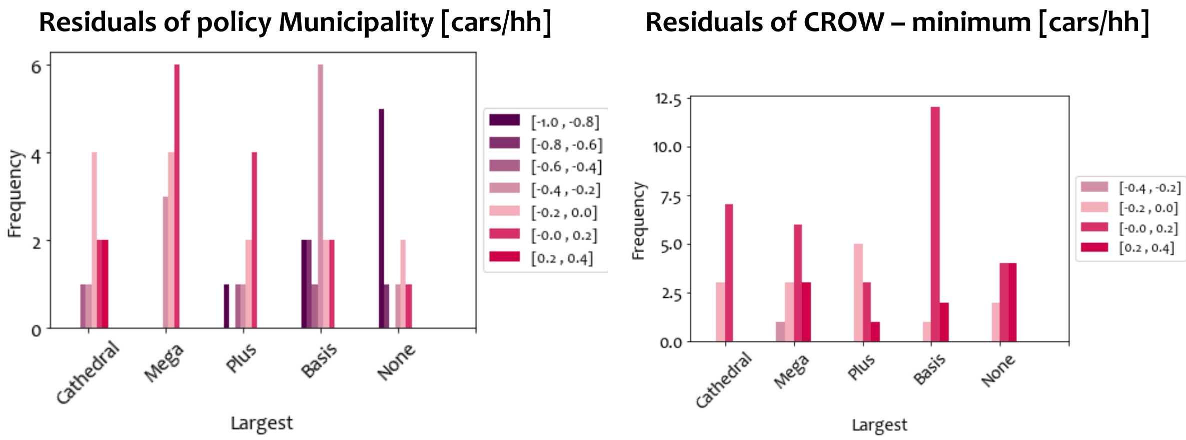


Figure 8-5 Frequency of residuals of the policy of the municipality and CROW minimum Key figures

Even more striking is the accuracy of the CROW Key figures: for the Cathedral and the Mega largest train station types are the minima of the bandwidths spot-on. Nonetheless, for the other neighbourhoods seems the minimum of the bandwidth too low for actual household car ownership. So, there follows that the minimum of the bandwidth may be a good estimation for the neighbourhoods with a Cathedral or Mega train station type on a 3km bike distance but that the minimum of the bandwidth cannot directly be applied for the other neighbourhoods.

Although the hypothesis was that municipalities use too high parking standards for neighbourhoods near large train stations, it seems the opposite to be true. Current parking standards seem accurate of the municipalities for rent apartments with the Mega and Cathedral within a biking distance for the neighbourhoods in the sample. The same holds for the minimum of the bandwidth of CROW's Key figures. Nonetheless, for the smaller train station types are parking standards required between the mean and the average.

8.2.2 Case study 2: Private terraced houses

The second case study is about private terraced houses, from the study of BPD (BPD, 2018) followed that especially at rent apartments are large relative differences between actual car ownership and the parking standards. To contrast the results of the rental apartments contains the second case study private terraced houses. The following characteristics of the neighbourhood are the selection criteria: less than twenty per cent of rent buildings, less than 20 per cent multi-family dwellings and the average house value. This combination of criteria led to selection neighbourhoods with a high percentage of terraced houses. Which is validated by visual inspections of satellite photos and maps of Kadaster.

In total contains this case study 119 *buurten* in a total of 47 municipalities. The largest number of *buurten* are not in biking proximity to any train station (48, see Table 8-2). Again, actual car ownership of the neighbourhoods is in line with the expectations form Chapter 5: average car ownership is higher at the areas with the smaller train stations or not any train stations. The average household car ownership higher at these locations than in the rental apartments, which is according to the expectations of Chapter 5 too.

Table 8-2 Descriptive statistics of average household car ownership of the neighbourhoods

	Cathedral	Mega	Plus	Basis	Stop	None
Mean	0.97	1	1.04	1.19	1.17	1.23
Min	0.97	0.95	0.92	0.9	1.14	1
Max	0.97	1.13	1.44	1.52	1.21	1.45
Count	1	4	17	46	3	48

Figure 8-6 shows comparable results with the first case study. The residuals of model D are again low, which indicates that the chosen neighbourhoods are no outliers. The municipalities' parking standards seem comparable with the average of the bandwidths of CROW Key figures. Nonetheless, again the minimum of the bandwidth seems better suited for the neighbourhood with a Cathedral in biking proximity than the other neighbourhoods. Figure 8-7 shows that there are hardly any overestimations of the municipalities for the terraced houses, but the residuals of CROW Key figures minima show particularly positive residuals. So, the municipalities have rather wide parking standards, while actual household car ownership lies between the minimum and the average of the CROW Key figures bandwidths.

So, although the expectations were that especially parking standards of rental apartments were too high, are more frequent large absolute overestimations of the municipal parking standards for the terraced houses, see Figure 8-7.

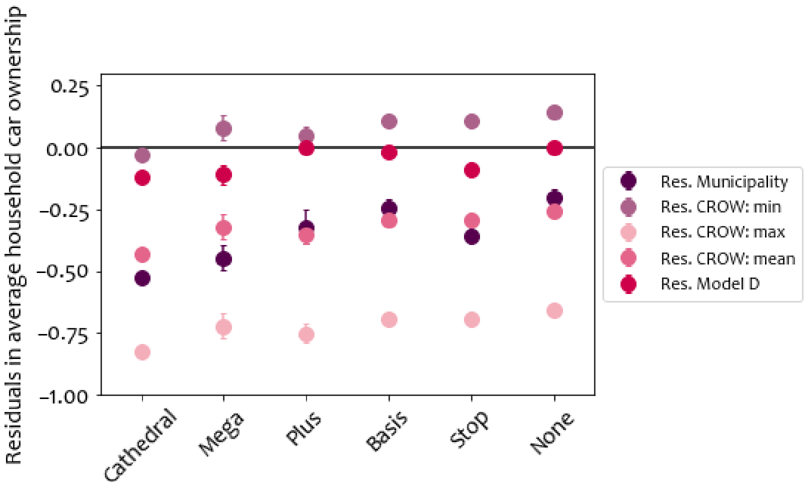


Figure 8-6 Comparison of residuals for private terraced housing with CROW, municipal policy and Model D of Chapter 5

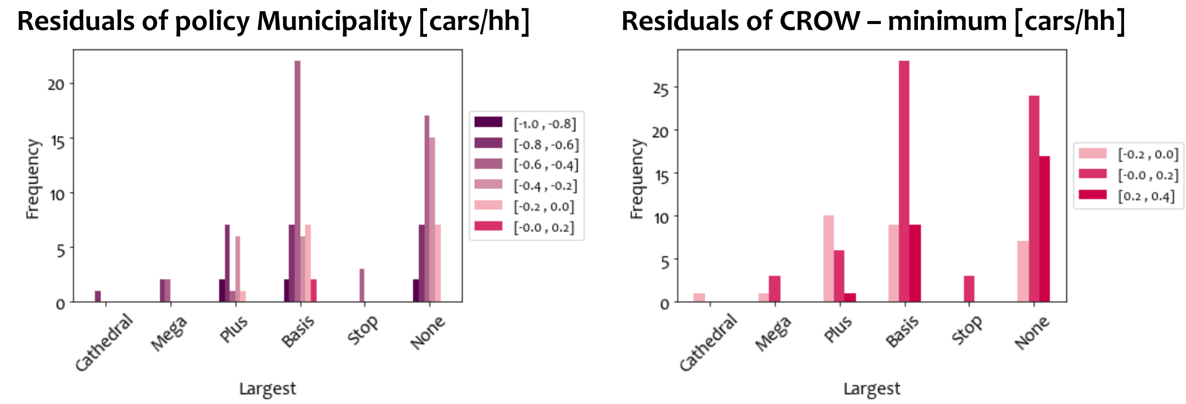


Figure 8-7 Frequency of residuals of the policy of the municipality and CROW minimum Key figures

8.3 Conclusion

The brief analysis of the residential parking policies of the municipality showed that there were large variations in the parking standards among the municipalities. Although the structures were similar, especially the definition of urban zones and differentiation of parking standards among residence types differed.

For the terraced houses, the case study showed that the average parking standards of municipalities are higher than actual average household car ownership. This difference was on average about 0.3: that is about one parking place extra for every three houses. The cases of rental apartments with a Cathedral or Mega train station in biking proximity had accurate current parking standards, whereas the parking standards for the rent apartments with the smaller train station types did not match with actual average household car ownership.

In a mental legacy to prevent parking nuisance in the neighbourhoods, it is not surprising that municipalities have higher parking standards than actual car ownership. Nonetheless, a small difference in actual car ownership and the number of required parking places can already lead to a high surplus of building costs. For example, Amsterdam applies relatively low parking standards to maintain the accessibility of the city. Many municipalities estimate their parking standards with the Key figures as foundation. They either have the principle to limit cars in the city or to limit nuisance in the neighbourhood by either low or a wide supply of parking places. Nonetheless, the actual effect of parking standards and parking supply on household car ownership is not known. Therefore is more research required to find out the influence of the parking policy on actual household car ownership and parking nuisance in the neighbourhood.

Although the differences seem relatively small at a household level, for apartment complexes with over the hundred apartments or new neighbourhoods are those differences significant in the building costs.

So, there is misfit of parking standards with actual car ownership at the rent apartments at smaller train stations and for terraced houses especially at the locations with the larger train station types. When the basis of parking standards are the key figures, an estimation of actual car ownership lies between the minimum and the average of the bandwidths. The minima are better applicable for the for "extreme" situations as residences in the proximity of the largest train stations. Nonetheless, at the other train station area are the minima of CROW insufficient indicators and it ambiguous which number suits actual household car ownership the best. Therefore, municipalities may need more tools than only the tables of the CROW key figures to determine parking standards that fit their local policy. So, the misfit of the parking standards of the municipality seems the largest when the minimum of the bandwidths is expected to be too low.

For the municipalities it would be recommended to use better approximations of actual car ownership and then determine the minimum or maximum parking standards according to the policy of the municipality goals.

Q5 *Where do parking standards not fit the actual demand?*

There are large differences in the parking standards of the municipalities. Although the structures were similar, especially the definition of the urban zones with different parking standards varied and the extent of differentiation of the parking standards among different residence types fluctuated. Two case studies are performed to analyse where parking standards do not fit actual demand. The expectations were that especially at residences near the larger train station types would have too high parking standards in comparison to residences near smaller train station or with not any train station in proximity. In reality were the parking standards for the neighbourhoods in the rental apartment case accurate for neighbourhoods with the largest train station types in proximity. The largest difference was for the terraced residences, independent of the proximity of train stations.

The minimum numbers for the CROW Key figures, national numbers that can be used for an indication of parking standards, are accurate for the largest train station types. Nonetheless, for smaller train station types holds that average household car ownership lies between the minimum and the average of the bandwidths. In concluding, the misfit of the parking standards of the municipality seems the largest when the minimum of the bandwidths is expected to be too low.

Therefore, municipalities may need more tools than only the tables of the CROW key figures to determine parking standards that fit their local policy. Furthermore, additional research is required to analyse the match of the application of the Key figures as parking standards with actual household car ownership.

9 Conclusion

The report aimed to quantify the relation of train stations and household car ownership to find out whether and where the application of current parking standards in the Netherlands can be improved. This chapter describes first the answers on the sub-questions and provides second the general conclusion of the main research question.

9.1 Sub questions

The following answers on the sub-questions have already been reported in the corresponding chapters. Nonetheless, the answers are for the overview of the reader again reported in this chapter.

Q1	*What is the effect of proximity to train stations on average household car ownership in urbanised areas?*

In the cross-sectional aggregated analysis for the year 2016, the proximity to train stations has a significant negative effect on average household car ownership. This relation even holds while controlling for other influencing factors of socio-demographics and built environment. The train stations were expressed in the following variables:

- Minimum distance (bike distance to nearest train station)

- Nearest train station type (category of daily passengers of train station that is at the smallest bike distance from the centre of the neighbourhood),

- The larger train station (whether there is a train station with more daily passengers in a bike distance of three kilometres of the centre of the *buurt)*

- Largest train station type (the train station in the category with the greatest number of daily passengers within a bike distance of 3km from the centre of the *buurt*). The variable with the classification of train stations in daily passengers in proximity of three kilometres is analysed in a separate multiple linear regression model. The following conclusions are:

- The larger the distance to the nearest train station type, the larger the average household car ownership. However, this effect is marginal in comparison to other influencing factors.
- The effect of train station types differs especially there is a large difference between the train station category with the most and the least number of passengers. For example, average household car ownership in a neighbourhood near the central train station in Amsterdam is 0.17 lower than a comparable neighbourhood with a small train station type as a nearest train station, for example, Hengelo Gezondheidspark.
- In case there is a larger train station than the nearest train station in a bike distance of three kilometres, the average household car ownership in those areas is even smaller.
- The train station in a bike distance of maximum three kilometres in the category of the highest number of daily passengers has the largest effect on average household car ownership: in comparison to no, or the lowest category is average household car ownership about 0.14 lower.

So, in general, have train stations a negative effect on average household car ownership in urbanised areas.

Q2	*What is the effect of new train stations on average household car ownership in urbanised areas?*

In an aggregated study to changes in neighbourhood characteristics in time are the influencing factors for changes in average household car ownership analysed. Although there are significant effects of the socio-demographics in line with the previous results, the changes of additions of train stations did not have a significant effect on average household car ownership. Nevertheless, only the two train station types with the lowest number of passengers (Basis and Stop) opened in the investigated time in just a small selection of neighbourhoods. Therefore, there can only be concluded that the addition of the train stations with the lowest number of passengers did not significantly affect average household car ownership of the neighbourhoods in the dataset.

Q3	*How do household car ownership and travel behaviour differ between consonant and dissonant residents in areas with and without train stations in proximity?*

In a cross-section study of the year 2014 of the Netherlands Mobility Panel, the analysis contains a comparison of household car ownership of dissonant and consonant residents. In line with previous research, are both the preference to live in a train station area and the presence of the train station areas of influence on the frequency of train use of the gatekeeper. Even more important, there is a significant difference in household car ownership between dissonant and consonant residents in train station rich areas. Nevertheless, there are some small differences in socio-demographics of the groups, which may have a (partial) explanation for the difference in household car ownership of the groups. Furthermore, there is a significant difference in household car ownership between the train station rich consonant and train station poor dissonant residents. So, both travel preference and built environment affect household car ownership.

Q4	*How does household car ownership change when people move to locations with different train station proximity than before?*

Changes in household car ownership of movers in the years 2014 and 2015 of the Netherlands Mobility Panel are analysed to find out whether train station areas have a decisive effect in acquiring or disposing of cars. The number of relocators in the sample is low, therefore is it not possible to have conclusions with a statistical significance. Nonetheless, the households have increasing household car ownership when the relocators move to areas with train stations with a lower number of passengers. These results indicate an effect of the built environment, but the characteristics and the reasons people have moved should be further analysed to conclude about the causality. Therefore, additional data should be acquired to get more insights into the choices in household car ownership.

Q5	*Where do parking standards not fit the actual demand?*

There are large differences in the parking standards of the municipalities. Although the structures were similar, especially the definition of the urban zones with different parking standards varied and the extent of differentiation of the parking standards among different residence types fluctuated. Two case studies are performed to analyse where parking standards do not fit actual demand. The expectations were that especially at residences near the larger train station types would have too high parking standards in comparison to residences near smaller train stations or with not any train station in proximity. Were the parking standards for the neighbourhoods in the rental apartment case accurate for neighbourhoods with the largest train station types in proximity. The largest difference was for the terraced residences, independent of the proximity of train stations.

The minimum numbers for the CROW Key figures, national numbers that can be used for an indication of parking standards, are accurate for the largest train station types. Nonetheless, for smaller train station types holds that average household car ownership lies between the minimum and the average of the bandwidths. In concluding, the misfit of the parking standards of the municipality seems the largest when the minimum of the bandwidths is expected to be too low.

Therefore, municipalities may need more tools than only the tables of the CROW key figures to determine parking standards that fit their local policy. Furthermore, additional research is required to analyse the match of the application of the Key figures as parking standards with actual household car ownership.

9.2 Main research question

While the previous section contained the conclusions of the different parts of the study, combines this section the results in one general conclusion. The first part of study aimed to define the influence of the proximity on household car ownership and the second part of the study aimed to use this information to formulate recommendations for the residential parking policy of municipalities. This general conclusion provides answers to the main research question:

Research Question	*What is the influence of proximity to train stations on household car ownership, and how can this relationship be used to improve parking standards in urbanised residential areas in the Netherlands?*

There is a significant effect of the proximity to train stations on average household car ownership in the neighbourhoods. Although, the effects of the distance itself were relatively marginal, are the effects of the different station types relatively larger. Especially, average household car ownership is lower in areas with a train station with more than 75000 daily passengers in biking proximity. These relations even hold while controlling for other variables in the built environment and the socio-demographics. On top of that, the same relations are observed at a disaggregated level.

Next, the causal relation of the proximity to train stations is analysed to find out whether the train stations are associated with or influence lower household car ownership. The addition of new train station did not have a significant effect on household car ownership. An important remark is that those new train stations were only the train station types with little to no effect on household car ownership. Therefore, only can be concluded that train stations with a relatively small number of daily passengers (smaller than 10000 passengers) have no significant causal effect in the sample of 2005-2015.

Since the aggregated studies did not contain the preferences and changes over time within households, is the causality of train stations analysed with another dataset too: Netherlands Mobility Panel (MPN). The first part of the analysis was about the residential preferences for train stations in proximity and actual car ownership, and the second part was about the changes in household car ownership during relocations from and to train station areas. In train-rich areas was a significant difference in household car ownership between people with the preference to live in proximity of a train station and who did not have that preference. On top of that was no significant difference between the last group and people with a train preference in a train-poor area. Therefore, the effect of train stations can only be partially attributed to the preferences of the residents and partially to the train stations itself. These results are in line with (X. Cao et al., 2019), although focussed this study on differences in residential urban areas.

The study to relocations showed when people moved to areas with a train station with fewer passengers at biking proximity, household car ownership increased. The combination of the three methods that investigated the causality question indicates that both the train stations itself as preferences influence household car ownership. Nonetheless, more research is required to gain more statistical significance and understanding of household choices.

Finally, the case studies showed that in general municipalities have a higher minimum required of number parking places in comparison to actual car ownership. The minimum numbers for the CROW key figures (national numbers that can be used for an indication of parking standards) are accurate for the largest train station types. Nonetheless, for smaller train station types holds that average household car ownership lies between the minimum and the average of the bandwidths. To improve parking standards are more advanced tools required to determine expected household car ownership. In this determination may the train stations, parking permits and the expected socio-demographics help for accuracy. Then, the municipality can define parking standards that better fit the specific new developments and fit the policy of facilitating or limiting cars.

So, in general, there is a significant effect of train stations on (average) household car ownership. This report indicated that both preferences and train stations are decisive in household car ownership, but more research is required to confirm these observations. So, this subject requires more research for the determination of the influence of trains station on car ownership. Nonetheless, in the parking policy is the proximity of train stations a subject that could lead to improvements in the accuracy. From the case studies followed that the correctness of the advisory key figures differs per train station type in the proximity of the neighbourhood. The case studies indicate that the minimum bandwidth of the CROW key figures are sufficient for neighbourhoods near the Cathedral train stations and for the other train stations are more customisations required. Therefore, it is recommended to develop more advanced methods in the determination of parking standards. So, the required number of parking places fit the policy of the municipality.

10 Discussion

This chapter reflects on the chosen methodology, interprets the results and has recommendations for further research. In this report was a variety of research methods applied to finally estimate the influence of the proximity to train station on household car ownership and to analyse were parking standards are a mismatch with actual household car ownership.

There are many studies to the influence of built environment and socio-demographics on household car ownership. Nonetheless, in studies from around the world, there is no agreement on the effect of proximity to train stations. The results consequently vary from hardly any to a reducing effect of train stations on household car ownership. Importantly, most of the studies only included the proximity to the train stations but did not consider the differences among the train stations. In the aggregated study to average household car ownership in the neighbourhoods was especially the effect of the different train station types important. Nonetheless, the presence of the train stations with the highest number of daily passengers has been limited to a dichotomous distance threshold. Academic studies show that in the travel behaviour follows a distance decay function. In further research, would it be recommended to make use of a distance decay function for the presence of this train station and the number of daily passengers.

In agreement with previous findings, especially socio-demographics did have a strong effect on average household car ownership. In addition to the prior knowledge, this study controlled for the local parking policy too: parking permits. Although not the main point of interest but in line with expectations, car ownership was lower in areas with limitations in (public) parking. Average household car ownership decreased in the order: 1. no parking permit required, 2. parking permit required and possible for at least two cars and 3. parking permit required and only possible for one car. Contrary to the expectations, the price of the parking permit of the first and second car did not have a significant effect on average household car ownership. To the best of the knowledge of the author are no previous studies to the effects of parking permits on household car ownership. So, although not the main goal of this study, does this study have a contribution to academic research by its findings of the effects of parking permits. The parking permits may correlate with the parking capacity and attractivity of the (surrounding) neighbourhoods. Therefore, it would be recommended for further research to gather data about the number of available private and public parking places and analyse their effect on household car ownership.

However most importantly, even with controlling for socio-demographics and built-environment, the train stations had a significant negative effect on average household car ownership. The negative effect of the number of passengers of a train station is probably not directly caused by the passengers themselves. The number of passengers is associated with the service-level of the train stations: so, the number of connections, the frequency of connection, accessibility, security etcetera. Nonetheless, this study was on an aggregated level. Therefore, the model cannot consider the variations within neighbourhoods. With aggregated data there is a risk of ecological fallacy: the conclusions may only be applicable for the neighbourhoods and not for the individuals. Plus, the travel distance to the train station varies among the households within the neighbourhood. Therefore, it would be recommended to repeat this study with disaggregated data.

Contrary to the expectations did car ownership not significantly change as a result of the addition of a new train station in the neighbourhood. Nonetheless, the explanation of this observation lies in the previous results. The new train stations were generally the train stations with a low number of passengers. Another explanation may be that the change of a new train station may be slower than the change of a neighbourhood in socio-demographics. Additional research to changes in household car ownership may be relevant for the development of new neighbourhoods or new train stations in already existing areas.

Furthermore, especially in train station areas is the self-selection effect is an important topic. Academics try to find out whether the built-environment influences car ownership or the people consciously select residential areas that match their travel preferences. There still lacked a Dutch cross-country study to influence of train stations on household car ownership with clear recommendations for Dutch parking policy. Therefore, this study focussed on the effect of train stations on car ownership and its implications for parking policy.

In line with expectations have dissonant households in train rich areas higher car ownership than consonant households. At new development locations in train station areas, it would be very important to attract households that match with train preferences. This would both be beneficial for the effectivity of the train station and the lower number of required parking places. Nonetheless, the dataset does not contain more information about why these households ended up in an area which does not match their travel preferences. Therefore, it would be recommended for further research to go deeper into the location choice factors.

On top of that would additional research to the socio-demographics of dissonant and consonant households be recommended. Nonetheless, this study contributes to the existing international literature that this relation is even applicable in the urbanised areas in a European country. In which, in comparison to countries from other continents are smaller differences in built environment (Ettema & Nieuwenhuis, 2017).

This study also showed that for example, income and age of residents had an important effect on average household car ownership. The ageing of the neighbourhoods may lead people's travel behaviour and car ownership changes over time, for example, a change in household composition, job or income. On top of that should be carefully paid attention to (future) trends as decreasing car ownership among young adults, shared economy and self-driving cars. Therefore, it would be recommended to analyse the ageing of neighbourhoods in train station areas with low parking standards to measure the changes in household car ownership, mobility and the parking nuisance of the neighbourhood.

The methods to analyse the effects of train station proximity on household car ownership varied in dataset and in approach. In all the methods and datasets was a significant effect of train stations and different train station types on household car ownership. The added value of the different methods were the probability to analyse the causality. Although the opening of new train stations showed no causal effect, the studies to preferences and relocations did indicate a causal effect. The greatest common divisor was in all the cases the small samples of data.

The case studies made use of the current municipal parking standards. The results show, therefore only if future development projects require a matching number of parking places with current actual car ownership. This leads to the limitation that the effects of the parking standards on car ownership were not a part of the scope. In parking policy have municipalities the option to facilitate the demand or to limit the supply. Nonetheless, the effect of these options is not studied in academic researches. Therefore, more research is required for the analysis of the influence of parking policy on household car ownership.

For the case studies was expected that especially the municipal parking standards would have the largest overestimation of number of required parking places. The opposite turned out to be true. The parking standards near the largest train station types for rent apartments were good approximations of actual household car ownership, but neighbourhoods in the proximity of smaller train station types had large overestimations. The expectation is that the municipalities recently adapted their parking standards to better matching numbers with actual car ownership. To improve the parking standards of a municipality are better and advanced tools necessary to approximate car ownership better. Plus research is required to the effects of limiting or either a facilitating approach for both the parking nuisance as actual household car ownership.

11 References

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12 Appendices

Appendix A Data description (Cross-sectional analysis)

This section describes the details of the data for the cross-sectional analysis. The level of detail, the characteristics and the enrichment of the dataset are discussed.

Appendix A.1 Detail levels of data

The most common levels of detail of national data are based on the postcode areas or the characteristics of the neighbourhood. They are listed and explained in Table 12-1. The advantage of *buurt* level is the expected homogeneity of the areas and the relatively small scale. However, the advantage of PC4, is that more open source data is available on PC4.

Table 12-1 Common detail levels of data in The Netherlands

Area	Description
PC6	The postal code in The Netherlands exists of four numbers and two letters in the format 1234AB. The postal codes are called into being by the Dutch postal service to better sort post and find addresses. The PC6 areas represent the postal areas with six symbols (the four digits and two letters). The data has a high level of detail, because a PC6 area usually consists of a (part of a) street. Recent national data on a PC6 level is mostly not open source because of privacy issues.
PC5	PC5 represents the postal code areas too but consists now of only the first five symbols (1234 A). The areas are larger than PC6.
PC4	Just as PC5, does PC4 represent the postal code areas, but now only the digits (1234). There is many open source data available on this spatial level.
Buurten	The name of this spatial level is translated by CBS neighbourhood area. The *buurten* are determined by municipalities and coordinated by CBS. A neighbourhood area is defined as a part of municipality, with a homogenous socio-economic structure or planning (CBS, 2019). CBS has open source data available of average socio-demographics, built environment, car ownership etcetera.
Wijken	*Wijken* are translated by CBS to neighbourhoods (CBS, 2019), since there is hardly any differentiation in the translations: the Dutch names will be used in this report. The *wijken* are clusters of *buurten*, the clustering is based on historical or urban planning grounds. Mostly, the *wijken* are dominated by a land use type (CBS, 2019). For this spatial level CBS has the same data available as on *buurt* level.

Appendix A.2 Characteristics of the dataset

The main source of data is CBS on *buurt* level. The area of the *buurten* differs, Table 12-2 shows that the more urbanised the neighbourhood the smaller the area. Larger areas may have a larger demographic variation. Plus a large difference between the areas may cause errors in the analyses of variables that represent distances to facilities. Figure 12-1 shows a density plot of the areas per urbanisation level. For all the urbanisation levels holds a relatively large variation in areas. With ArcGIS minimum bounding circles are created for the buurten. On average the diameter of those circles is more than 1km. That means that the actual average as the crow flies distances to facilities may lie on average 0.5 km further or nearer. Network distances may even very more.

Table 12-2 Average area of land of buurten

Urbanisation	*Average area of land [ha]*	*Average area of land in sample[ha]*	*Frequency in sample*
1 Extremely Urbanised	*32*	*37*	*1069*
2 Strongly Urbanised	*50*	*52*	*1332*
3 Moderately Urbanised	*76*	*68*	*540*
4 Hardly Urbanised	*129*		
5 Not Urbanised	*460*		

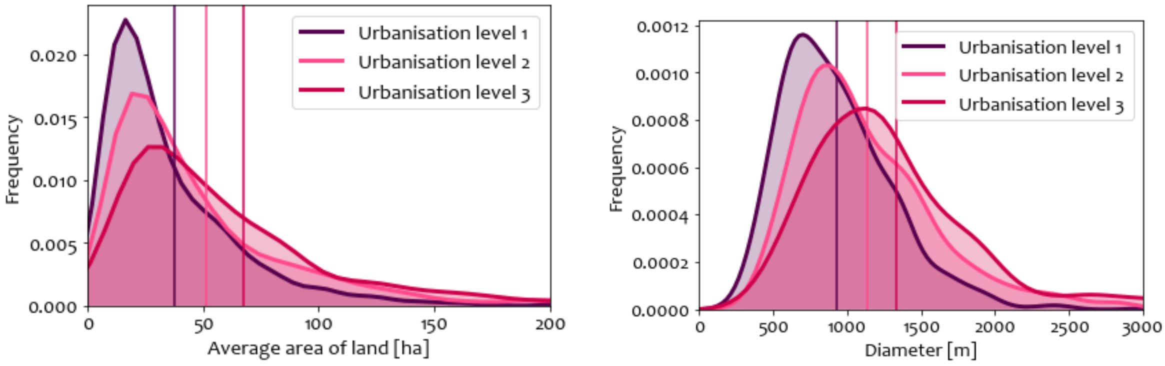


Figure 12-1 Density plot of average area of land for buurten in sample, the vertical lines represent the average area

The bar plots in Figure 12-2 illustrate the sizes of municipalities that are in the dataset. The

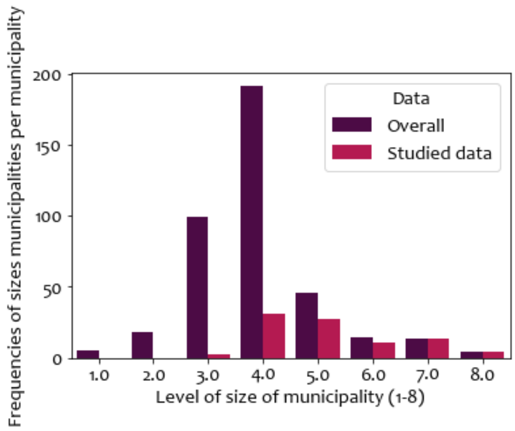


Figure 12-2 Overview of buurten and municipalities in the dataset per size of municipality

Appendix A.3 Enriched data

This section shows how the enriched data is obtained and provides some insights in the enriched data.

A.3.1 Public Transport and Accessibility

In the CBS dataset are the distances to nearest train stations and transfer stations already included. Nonetheless, these two variables do not contain information about which stations are transfer stations. Therefore, new variables are constructed.

The locations for the train stations are from Esri Nederland, based on the NS train stations list. The typology of the of the different type of stations is from ProRail (Prorail, 2019). The type "Cathedral" is the largest station type with more than 75,000 daily people embarking and disembarking the trains and the type "Stop" with the lowest daily amount of people (maximum of 1,000).

The distances are determined by the ArcGIS' Network Analyst with a bike network and bike speeds (Bikeprint, 2016). The nearest route is determined by minimizing the total travel time for each train station from the centroid of the *buurt.* Although this approach results in a large dataset, now it is possible to select only the nearest train station, but the amount of train stations within a specific network distance and the minimum distances per train station type too. However, the centroid may not be the most representative location for all the households in the *buurt*. Table 12-3 shows an overview of the specifications of the different station types.

The largest number of neighbourhoods have the Basis station as nearest station, this could be explained by the high frequency of the trains. The Plus stations have more than twice the average amount of *buurten* in the neighbourhood. This could have three reasons: the *buurten* are smaller near those stations, the neighbourhoods are located around the station and more *buurten* near larger stations are more urbanised.

The train station in Schiphol (*Cathedral* in South of Amsterdam) seems a large exception, that station is situated near hardly or not urbanised areas. This exception can be explained by the fact the station is located near Schiphol airport, so in the direct neighbourhood of the station there are hardly any residences. This could explain the relative low average number of neighbourhoods near the station. On the other hand, perhaps in the neighbourhood of the Cathedral stations are smaller stations located too. Therefore, the range of *buurten* decreases.

Table 12-3 Frequencies of station types

Station Type	*Nr people (dis)embarking*	*Frequency*	*Frequency of nearest buurt*	*Avg number of buurten near station*
Cathedral	*< 1 000*	*7*	*105*	*15*
Mega	*1 000 – 10 000*	*17*	*411*	*24*
Plus	*10 000 – 25 000*	*30*	*795*	*27*
Basis	*25 000- 75 000*	*217*	*2487*	*11*
Stop	*> 75 000*	*129*	*421*	*3*

Table 12-4 shows that the differences in area of land are not only varying for urbanisation level (see Table 12-2), but for the station types too. This may result in less reliable results for the smaller areas.

Table 12-4 Frequencies and land area per urbanisation level and station type

Station Type	Extremely Urbanised	Strongly Urbanised	Urbanised	Extremely Urbanised	Strongly Urbanised	Urbanised	All
Cathedral	71	24	6	37	47	62	41
Mega	221	104	29	36	60	61	45
Plus	283	298	89	32	49	64	44
Basis	455	779	345	41	52	72	53
Stop	39	127	71	36	51	56	50
			Car ownership			*Average area of land [ha]*	

As already indicated, the distances are determined by the distance from the centroid of the *buurt* to the train station. The centroid is the geographic centre of the *buurt*, but not the demographic centre; the housing may not be homogenous spread over the *buurt*. Taking into account the radius of the *buurten*, the actual centre may differ on average with as the crow flies distances of 0.5 km. The network distance may even be larger. On top of that a bike network has been used to determine the distances, instead of a CBS' car network. The calculated network distance is compared with the weighted average network distance to train stations of the CBS dataset in Figure 12-3. In general, the differences of the distances are in the expected interval of -0.7 to +0.7 km.

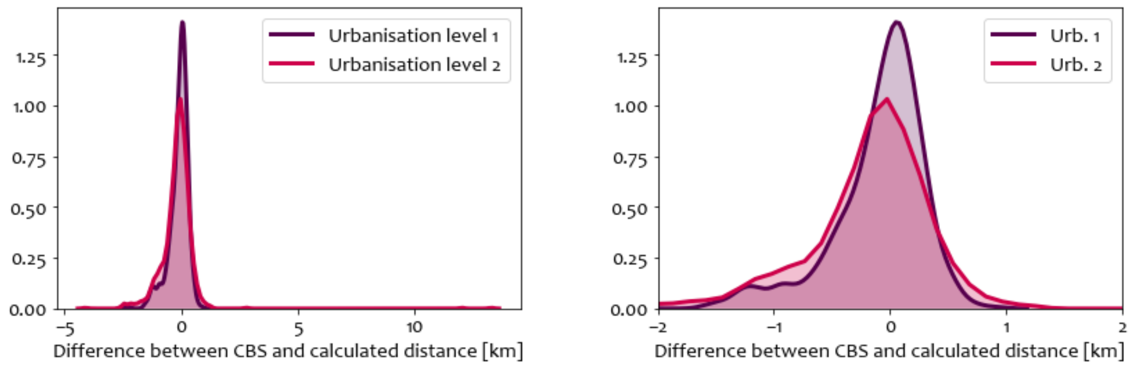


Figure 12-3 Difference between CBS and calculated distance to train station (Zoomed-in version at the right)

Finally, bike and ride accessibility is added into the dataset too. The University of Twente is the source of the dataset. The variable indicates the total number of jobs that are accessible by bike and public transport. This variable is however on PC4 level. To match this data into the set, an already existing CBS variable is used: most occurring PC4 within *buurt.* So, for each *buurt* the accessibility of the most occurring PC4 is joined with the dataset. Figure 12-4 shows an example of Amsterdam where random colours indicate the PC4s.

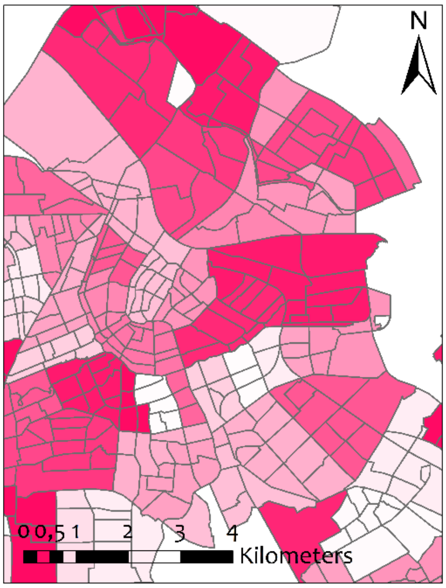


Figure 12-4 The buurt areas (grey edges) with random colours per highest overlapping PC4 in Amsterdam

A.3.2 Entropy index

The entropy index is based on the land use areas per *buurt*. The CBS dataset contains areas of land use types of the year 2015. Based on the literature study the land uses types are grouped into residential, business and green area. The green area contains nature, recreation and water. The business contains all the built areas minus residential areas. The determination of the entropy index is as formula 2-1.

A.3.3 Job density

The number of jobs is approximated on the area of businesses. The floor area of buildings and the main type of use is available by Kadaster. For the different types of building uses Goudappel Coffeng has indicators for the average floor area per job/full employee. For each business building the amount of jobs are determined and for each buurt the sum of the jobs of the business divided by the total land area is the job density.

A.3.4 Buildings

The data of Kadaster is used for the determination of building year and floor area too. The dataset is from 2018, because the dataset of 2016 had many missing values for the floor area and didn't contain the main type of use as residential, health etcetera. The objects of Kadaster are matched with ArcGIS to their neighbourhood. From the table of every single object with the building years and floor areas, the variables about the buildings could be obtained by grouping the specific data.

A.3.5 City Centre

There was unfortunately no data available with areas of the city centres. Therefore, the city centres are obtained by the author with an expert view. With ArcGIS, the minimum network distances from the centroids of the *buurten* to the centroids of the city centres are the determined. So, for each *buurt* the minimum distance to a city centre could be obtained.

A.3.6 Parking Costs

RDW operates an open source database of parking data. This database contains information about the parking areas, operators, capacity, costs etcetera. The dataset contains a great selection of the payed parking places of The Netherlands. The characteristics of the parking areas are time and day dependent and the dataset is in a relational structure. The data preparations consisted of matching all the relational tables into one large table. The matching was based on the data description of

RDW. Then, only the records are kept for Tuesdays between 10 and 11 o'clock: a regular day at a specific time interval during working hours. The prices were available for different time steps (e.g. costs per 20 minutes or costs per 8 minutes). Therefore, all the costs are redefined as price per hour. Finally, the costs of the parking places are aggregated to *buurt* level. The average parking costs per hour are weighted by the area of the parking places in that *buurt*. The capacity of the parking area would have been a better factor to weight the parking prices, but the availability of this characteristic was less than 25% of the parking areas. Therefore, the surface area of the parking areas is expected to be a better weight factor. Figure 12-5 shows example maps of the costs per parking area and average costs per *buurt*.

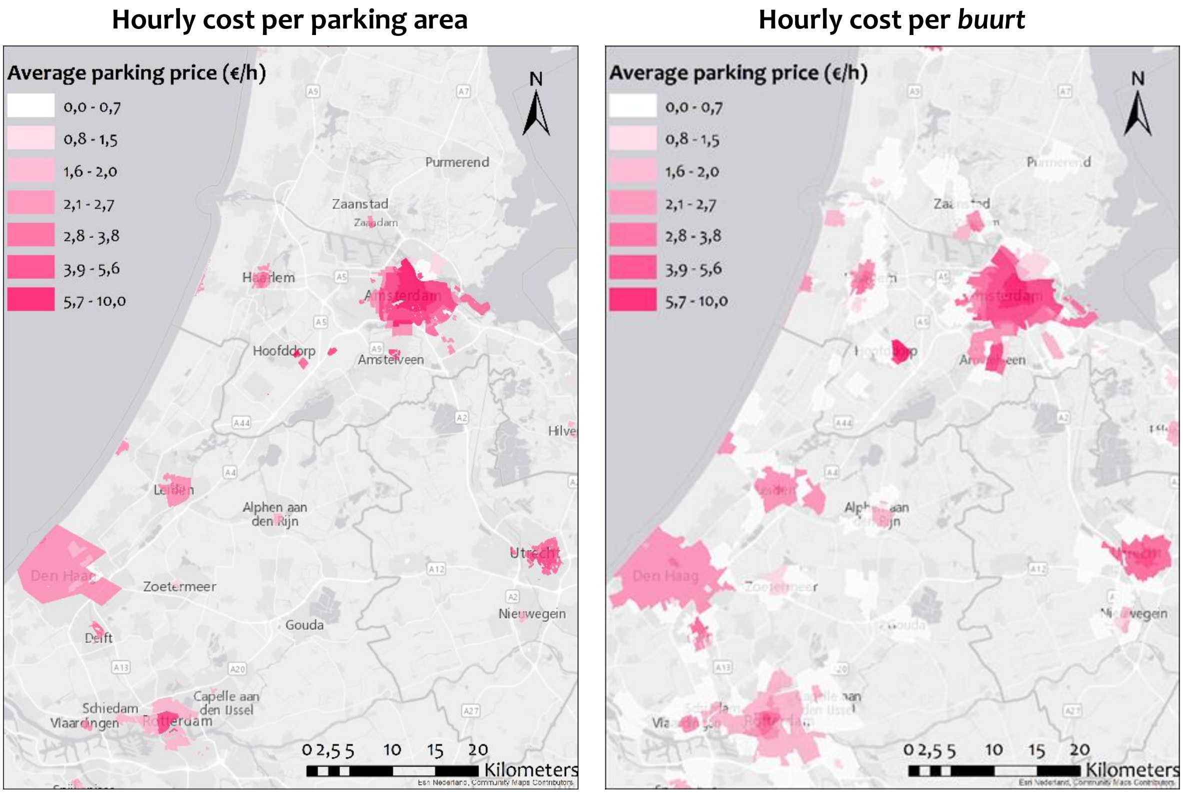


Figure 12-5 Original and processed data in example map of Randstad

A.3.7 Parking permit

The dataset of the parking costs (RDW, 2018) contains geographical information about parking permit areas. In those areas the residents are required to afford a permit to park their car(s). Unfortunately, the areas are only available for a small selection of the municipalities and the data doesn't contain information about the costs for the cars. Therefore, the author constructed a new dataset about parking permits per *buurt*. For each municipality in the sample (in total 91), the website is visited and the parking permit areas, costs for first car, costs for second car and the timeframe the cars are allowed to be parked are analysed. For each *buurt* in the sample, the variables: yearly parking costs for first car, yearly parking costs for second car and type of parking permit are constructed. Figure 12-6 shows an overview of the parking permit variables in maps of the Randstad.

In some municipalities there were next to or instead of parking permits parking releases. Mostly in those areas the parking for visitors is limited to a specific time frame of for example two hours. In case the parking release was not for free, the parking release is treated like a parking permit. The parking costs are excluding the legal dues which vary for the municipalities.

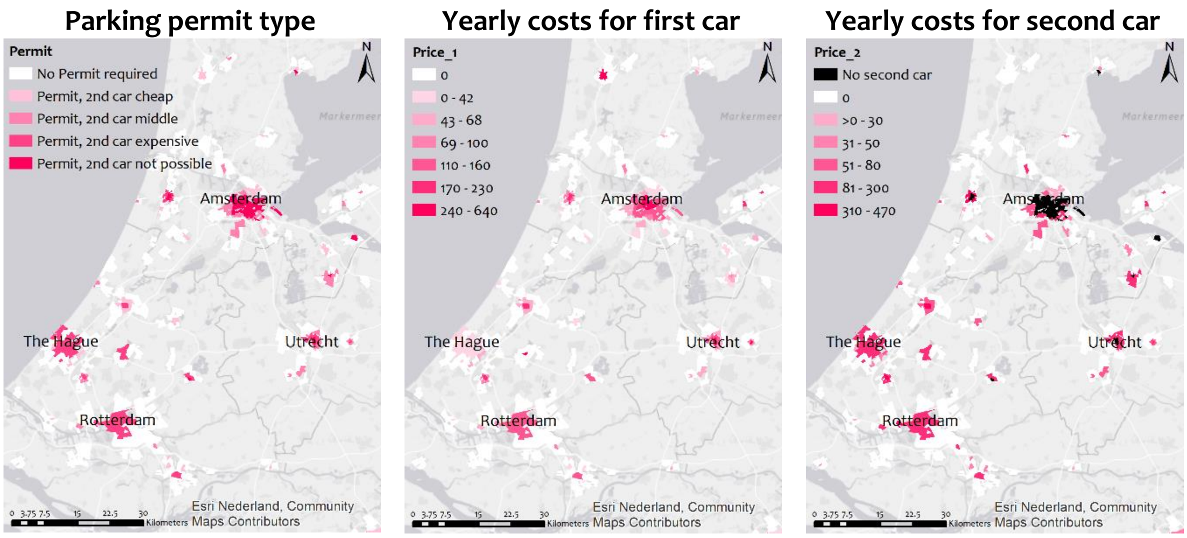


Figure 12-6 Maps with the parking permit variables

Appendix A.4 Data overview

Variable	Name in code	Detail level	Mean *modus	Standard deviation	Min	Max
Average household car ownership	auto_hh	*Buurt*				
Density						
Density of residents	bev_dichth	*Buurt*				
Density of residents	bev_dich_wk	*Wijk*				
Density of residents	bev_dich_gm	Municipality				
Urbanisation level	sted	*Buurt*				
Urbanisation level	sted_wk	*Wijk*				
Urbanisation level	sted_gm	Municipality				
Diversity						
Entropy index	Entropy	*Buurt*				
Entropy index	Entropy_wk	*Wijk*				
Job density	job_density	*Buurt*				
Job- housing ratio	ratio_job_resident	*Buurt*				
Design						
Network distance to (nearest) strongly urbanised city centre	Netw_dist_centre_12	*Buurt*				
Centre, shell or other built-up area	Schil	*Buurt*				
Public Transport and Accessibility						
Nearest train station type	min_distance					
Distance to nearest train station	min_station_type					
Density of bus stops		*Buurt*				
Bike and ride Accessibility	Average	PC4				
Socio-demographics						
Percentage of households with lowest 40% of income	p_hh_li	*Buurt*				
Percentage of people with income	p_inkont	*Buurt*				
Average household size	gem_hh_gr	*Buurt*				
Percentage of rental properties	p_huurw	*Buurt*				
Average building value	woz	*Buurt*				
Class of building value	price	*Buurt*				
Average income of residents	g_ink_pi	*Buurt*				
Percentage of people with age between 0-14	p_00_14_jr	*Buurt*				
Percentage of people with age between 15-24	p_15_24_jr	*Buurt*				
Percentage of people with age between 25-44	p_25_44_jr	*Buurt*				
Percentage of people with age between 45-64	p_45_64_jr	*Buurt*				

Percentage of people with age 65+	p_65_eo_jr	*Buurt*
Average building year	Bouwjaar	*Buurt*
Average surface area	average	*Buurt*

Appendix B Influencing factors of car ownership (Cross-sectional analysis)

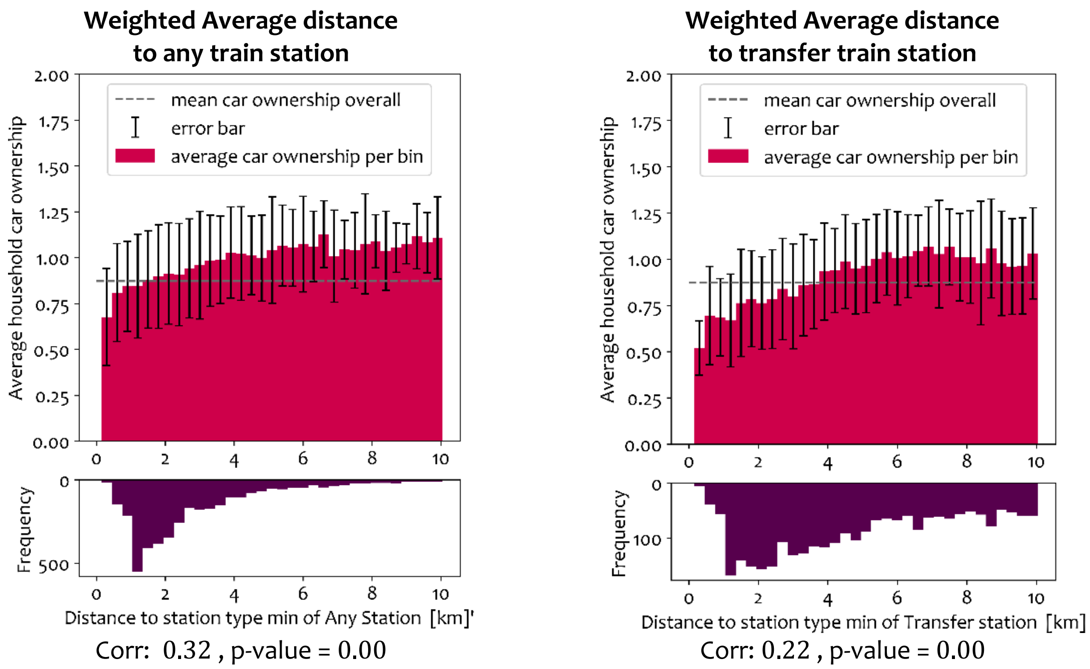
The individual relationship between the variables of interest and car ownership will be explored. Data of Appendix A is the basis of this Appendix. Maps, histograms and additional graphs make the relations visual.

Appendix B.1 Train stations

The relation of the distance to train stations is main subject of this study. The dataset of CBS 2016 includes weighted average distances to nearest train stations and nearest transfer stations. However, the dataset is enriched with average nearest distances to different stations types of ProRail too. The enriched data will provide the probability to analyse the effect of train stations on car ownership with more differentiation.

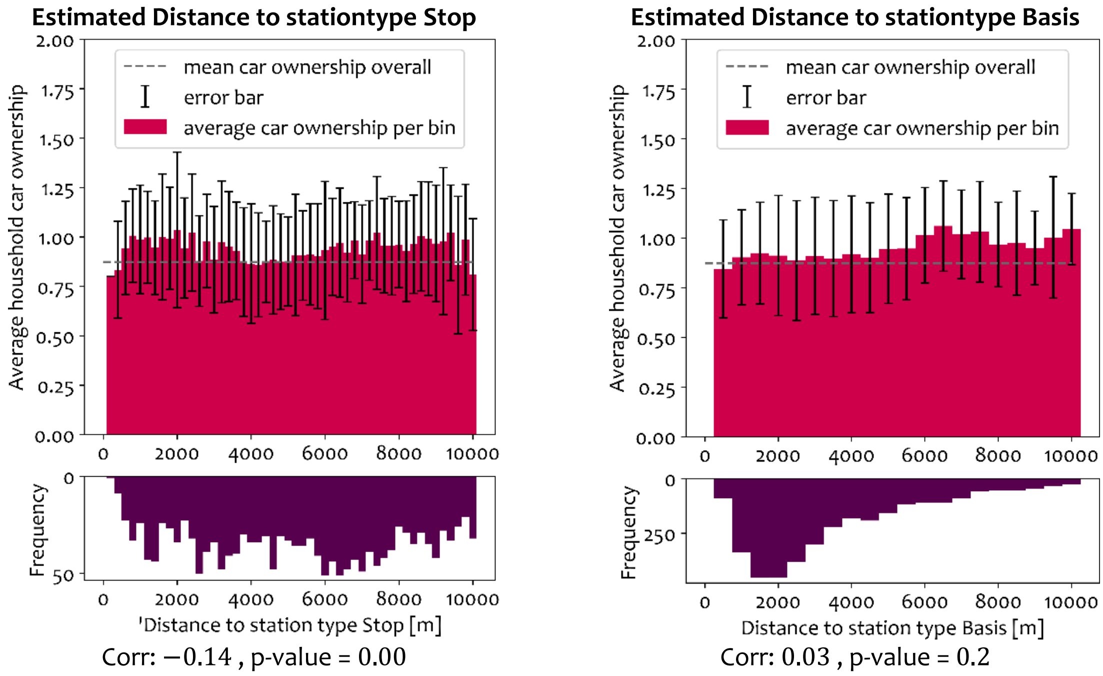
The effect of transfer train stations on average car ownership is stronger than the effect of any train station; the average car ownership of area within 4 km is lower than average household car ownership, while for any station this effect is only visible for areas within 1.5 km. Nevertheless, there is a higher correlation of the weighted distance to any station than to transfer stations.

Table 12-5 Relations of car ownership with distance to train stations



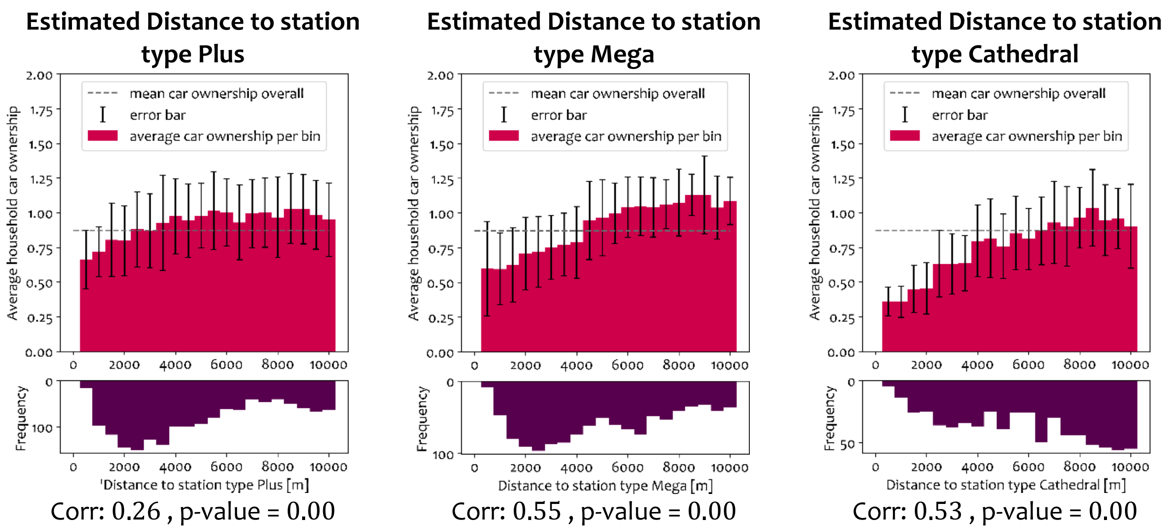
There seems to be hardly any effect of the smallest stations on car ownership, see Table 12-6. Surprisingly, the smallest stations are negatively correlated with car ownership. Potentially, the negative correlation is a result of the relative low frequency of neighbourhoods near smaller stations (despite the significance), see Table 12-3 too.

Table 12-6 Relations of car ownership with distance to smallest stations: Stop and Basis



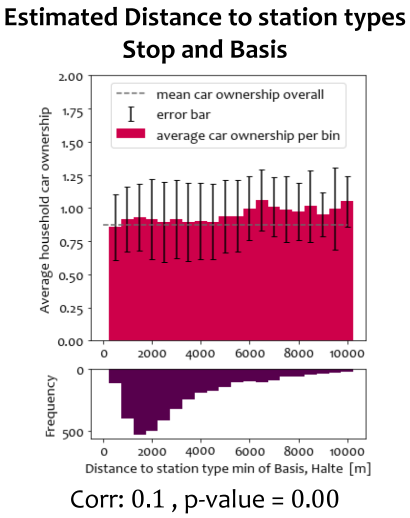
The relations of the bigger stations are more in line with the expectations, see Table 12-7. Especially the largest two stations have high positive correlations with car ownership. So, for these stations holds the nearer the station, the lower the car ownership.

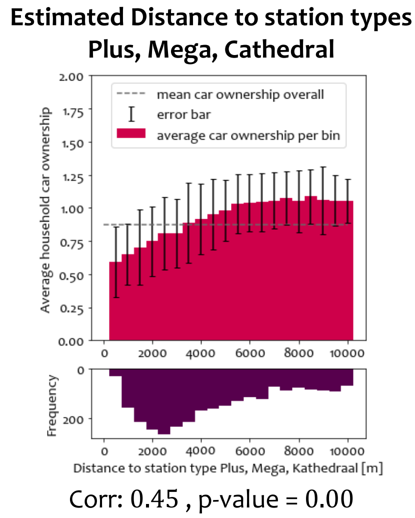
Table 12-7 Relations of car ownership with distance to the largest stations: Plus, Mega and Cathedral



From Table 12-7 followed that the distances to the Plus, Mega and Cathedral stations did have the largest impact on car ownership. Therefore, for each neighbourhood the shortest average network distance to either a Plus, Mega or a Cathedral station is determined, see Figure 12-7. The average network distances to the smallest two train station are determined too. Table 12-8 shows a combined result of the relations between car ownership and the smallest stations and between car ownership and the largest stations. Indeed, the smallest stations still have a smaller effect on car ownership than the largest stations.

Table 12-8 Relations of car ownership with distance to the smallest stations and largest stations





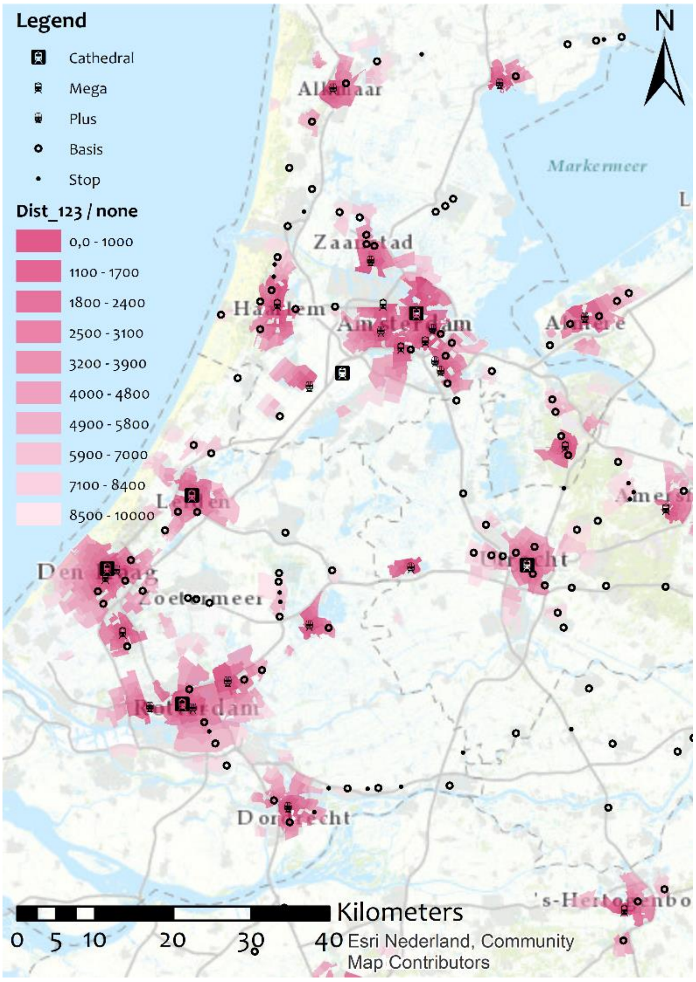
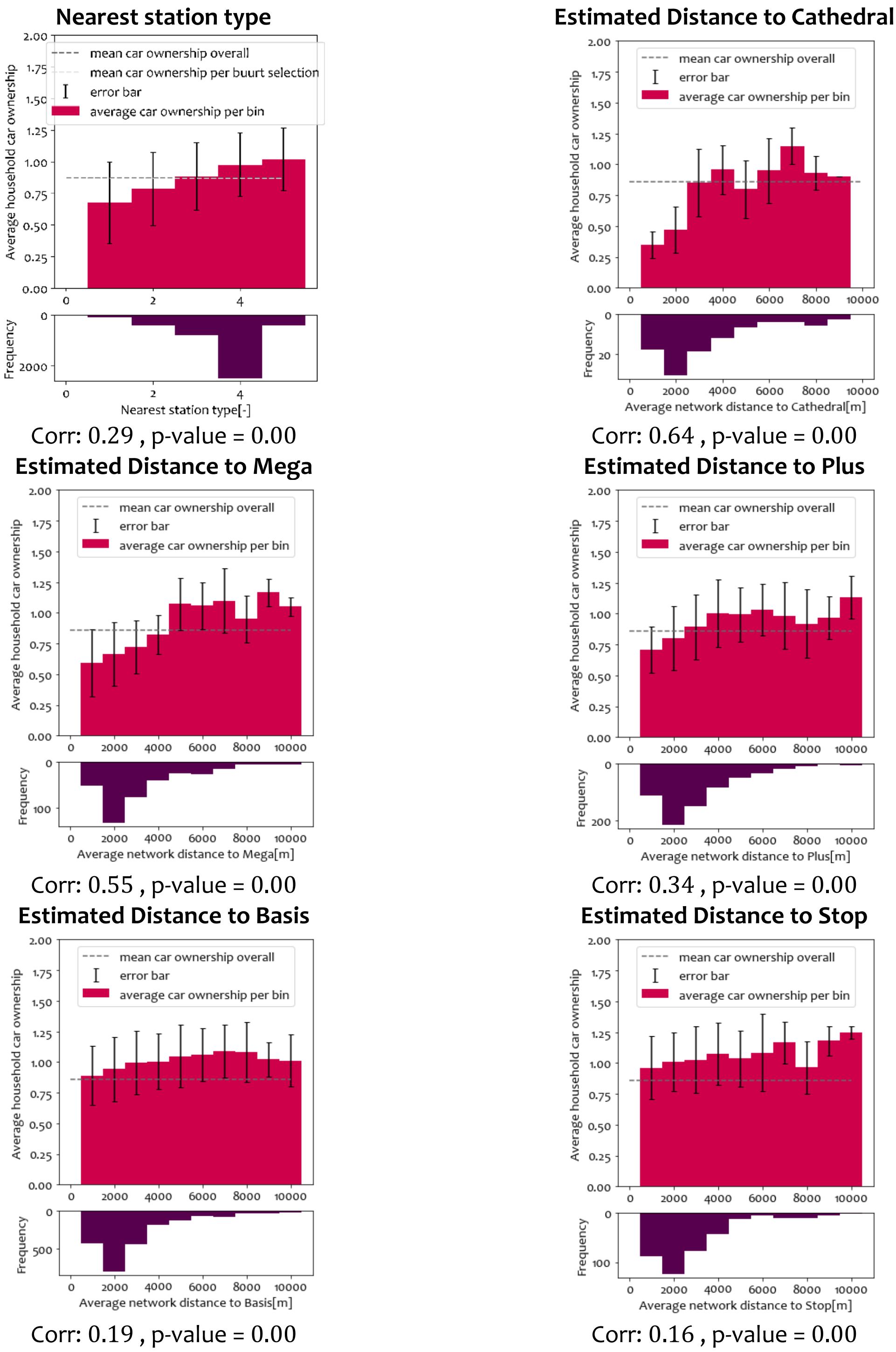


Figure 12-7 Distance to largest stations in urban areas

Another approach to analyse the relation of distance to train station and car ownership is to determine for each *buurt* which station type is the nearest. Table 12-9 shows the result of this analysis. Again, it turns out that the bigger the station type, the larger the effect on car ownership. So, people in neighbourhoods near large train stations have on average lower car ownership than people living near smaller train stations.

Table 12-9 Relations of car ownership with nearest station type and corresponding distance



The previous analyses were limited to only the nearest station. Potentially, not only the nearest station but other stations in the neighbourhood have influence on car ownership too. Therefore, the number of stations within a buffer of 5 km network distance from the *buurt* are counted.

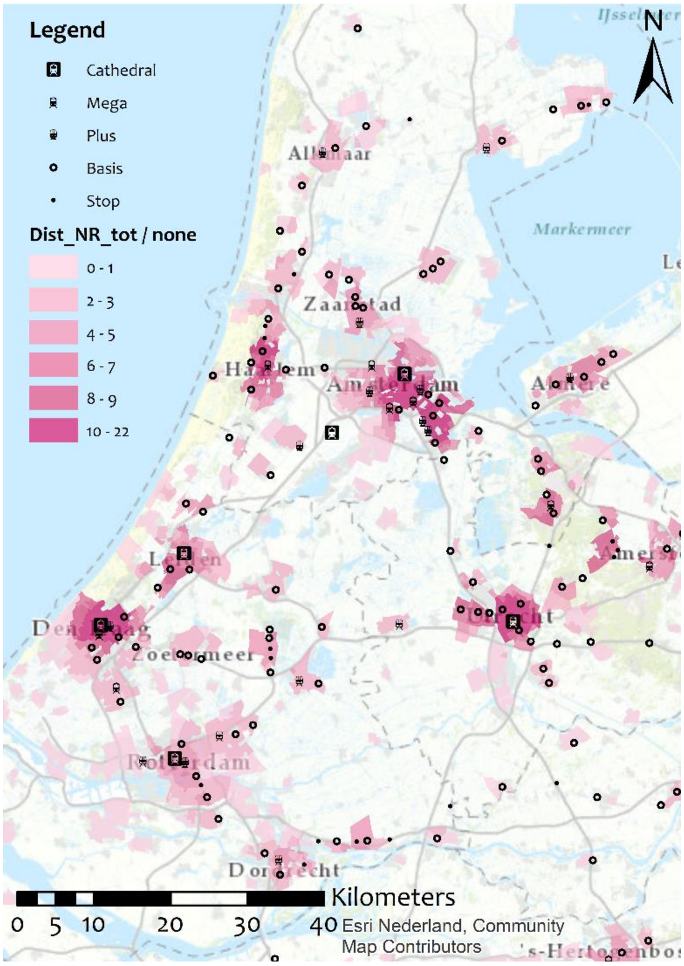
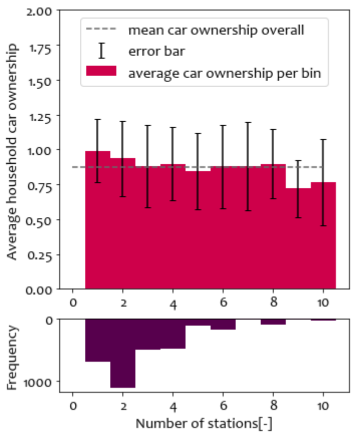


Figure 12-8 Number of largest stations within an average distance of 5km in urban areas

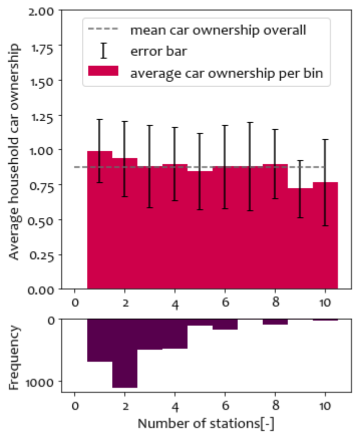
When the number of stations in the neighbourhood decreases, car ownership increases. However, this effect is very small in comparison to the effect of average network distance to nearest train stations.

Number of stations within buffer of 5 km



Corr: −0.23 , p-value = 0.00

Number of stations within buffer of 5 km Plus, Mega, Kathedraal

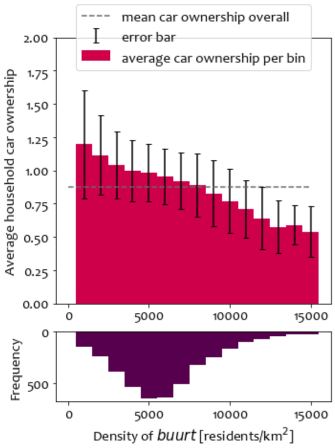
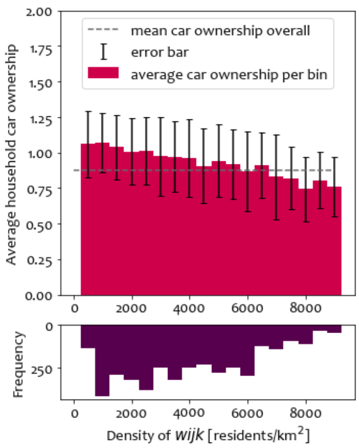
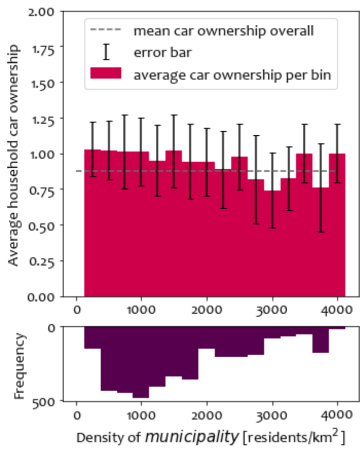


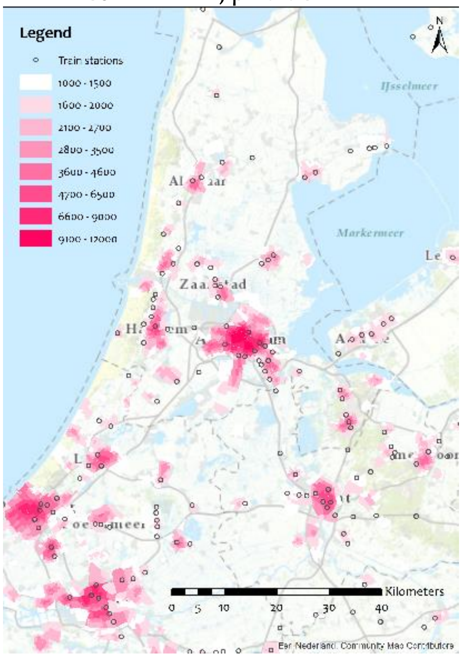
Corr: −0.20 , p-value = 0.00

Appendix B.2 Density

The density of the neighbourhood will be expressed in number of residents per km² and the number of jobs per km². Table 12-10 shows the average results of the relation between density per spatial level and average household car ownership per buurt. The Pearson correlations and the graphs are calculated for the three spatial levels *buurt*, *wijk* and municipality for average household car ownership on *buurt* level. The bins of the graphs represent average household car ownership of the units within the bin. When the density increases, average household car ownership decreases. The effect of direct neighbourhood (*buurt*) is larger than the larger neighbourhood (*wijk*) or even municipality. As expected, there is a significant negative relation between density and car ownership, when there are no other variables are included in the analysis.

Table 12-10 Relation of car ownership with urban density

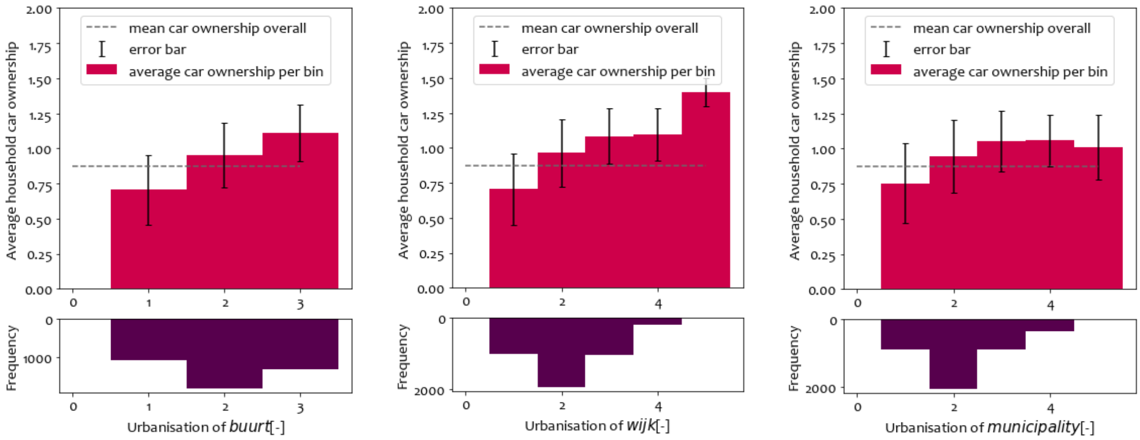
Buurt	**Wijk**	**Municipality**
		
Corr: −0.44 , p-value = 0.00	Corr: −0.35 , p-value = 0.00	Corr: −0.25 , p-value = 0.00



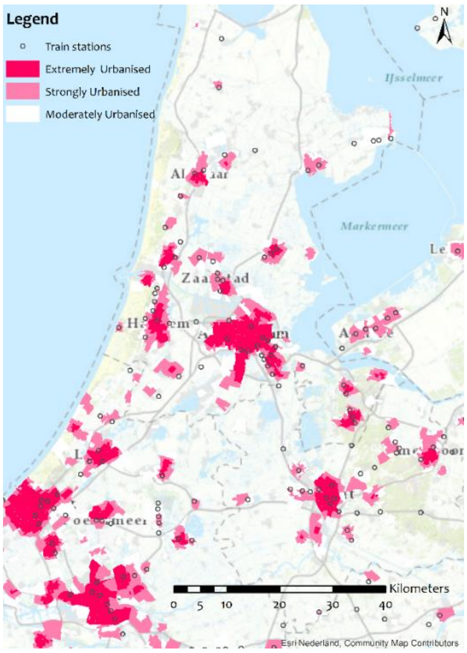
The urbanisation levels of the neighbourhoods are based on the densities of the units. Urbanisation levels are in a way discretized densities. The correlation between car ownership and urbanisation levels is high: the higher the urbanisation level (in this case the lower the value for urbanisation), the lower the household car ownership. The relation on *buurt* level is stronger than the relation on *wijk* or municipality levels.

Table 12-11 Relation of car ownership with urbanisation levels

Buurt **Wijk** **Municipality**



Corr: 0.55 , p-value = 0.00 Corr: 0.49 , p-value = 0.00 Corr: 0.35 , p-value = 0.00

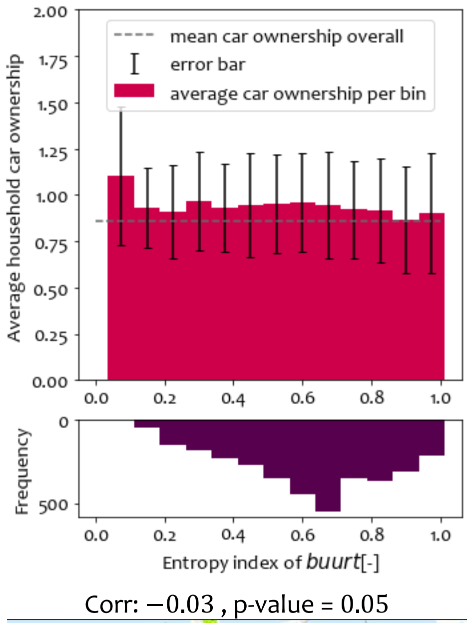


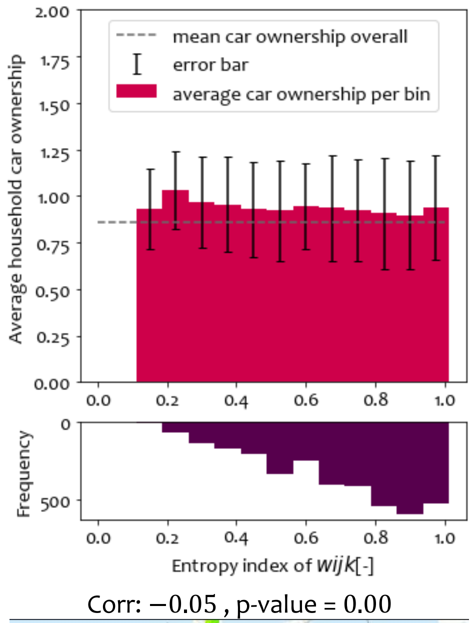
Appendix B.3 Diversity

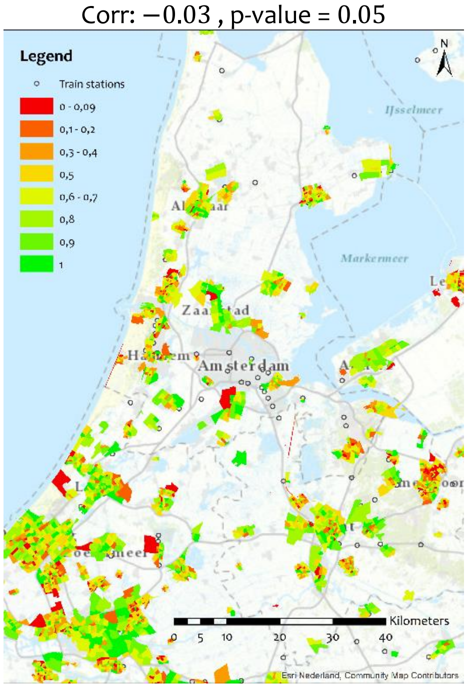
The diversity of land use is measured by the entropy index. The proportions of the area of residences, green (recreation and nature) and remaining build-up area (public, offices and commercial area) are compared. The index equals 1 if the different land use types are equally divided, the index equals 0 if there is only one land use type present. From literature followed that the higher the diversity, the lower car ownership. This relation is found too, but the effect is very limited and on *buurt* level not significant. This result may be a result of several reasons. The first reason is that it is only based on the values CBS had available for land use. The second reason is that green is added into this index, just as in literature. The addition of green may lead to score the suburbs the highest. The last reason may be the lack of data, as the maps in Table 12-12 already show, not for every neighbourhood there was data available to calculate the entropy index.

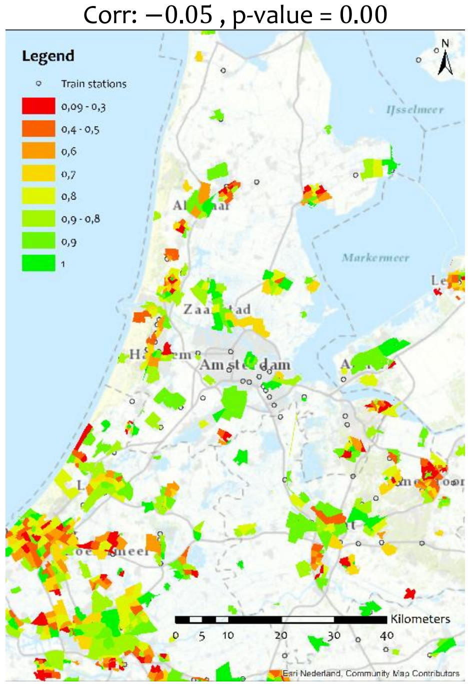
Table 12-12 Relation of car ownership with diversity of land use

Buurt	***Wijk***





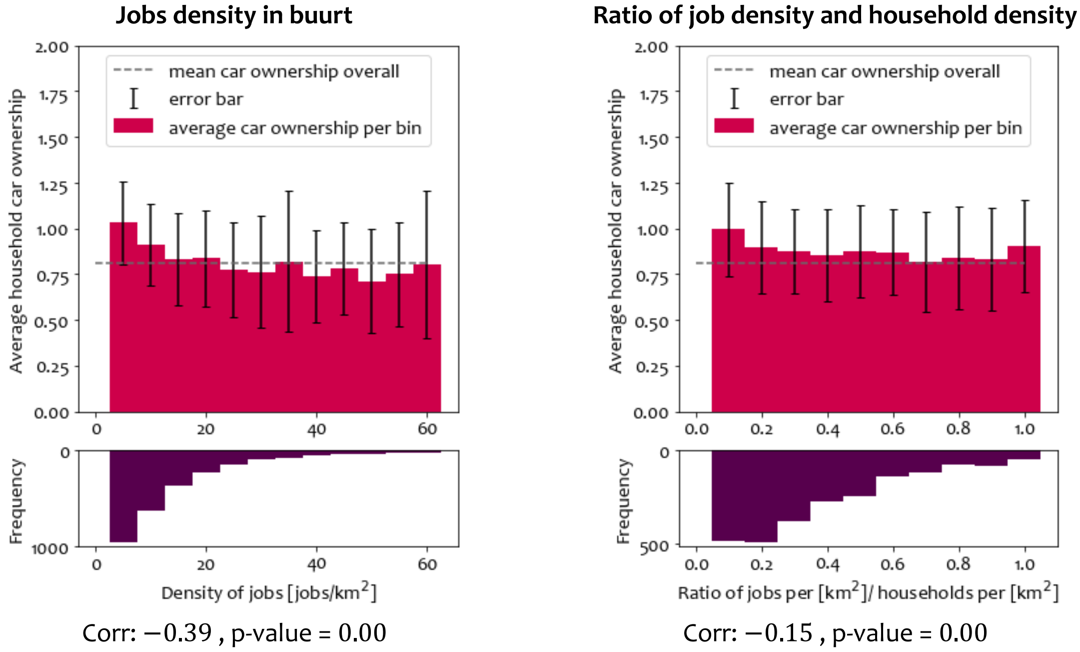




The number of jobs per km² and the ratio of jobs and housing per km² should represent the diversity too. The number of jobs are not actual measurements but are based on average floor areas per worker for the type of business (office, industry, health care etc.). The floor areas and type of business are determined with 2018 BAG data.

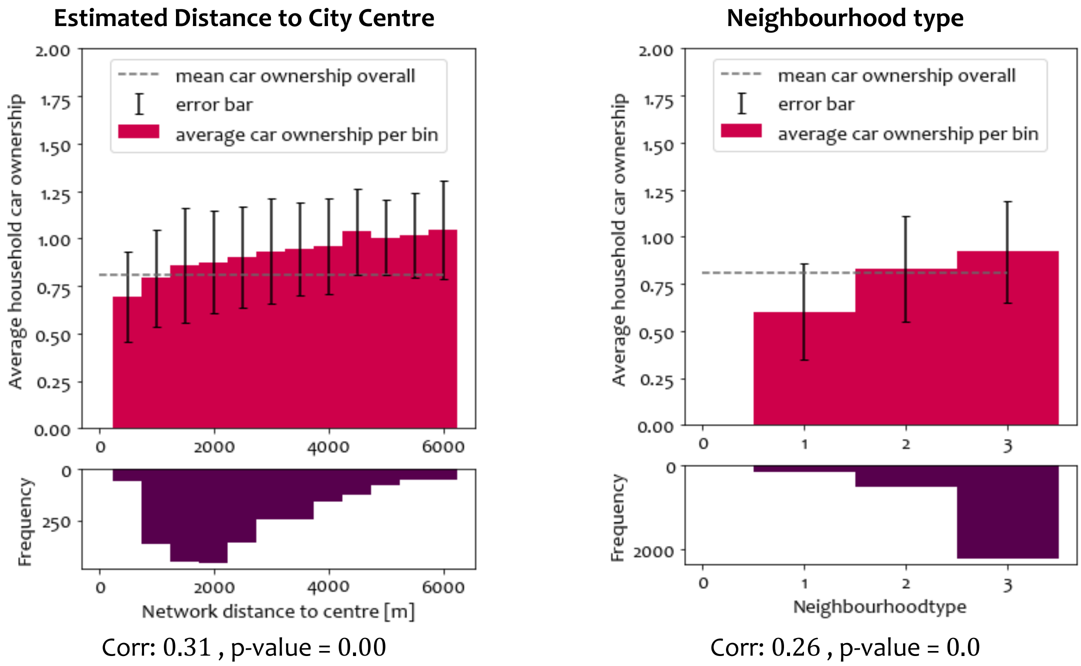
There is a significant negative relation between job density and car ownership. So, they higher the job density the lower average household car ownership. The same counts of the ratio of jobs and housing however that relation is less correlated.

Table 12-13 Relation of car ownership with job density



Appendix B.4 Design

Table 12-14 Relations of car ownership with distance to city centre and neighbourhood type

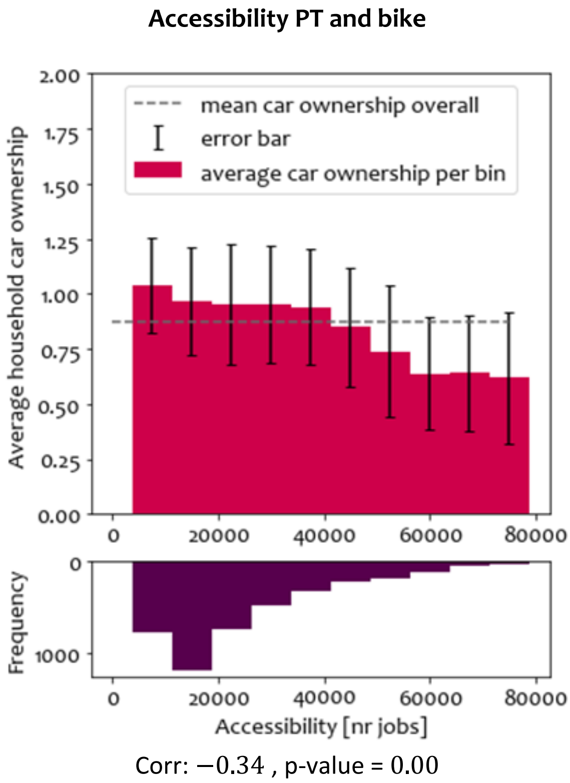


The design of the neighbourhood is defined by the distance to the centre and the type of neighbourhood. The type of neighbourhood is based on distance to centre too. The three different types are: 1. City Centre, 2. Shell of Centre, 3. Built-up area. This typology of the neighbourhoods is used by CROW to define the neighbourhoods. A more continuous way to define the neighbourhood is the estimated network distance to centre. Table 12-14 shows that the continuous variable, the distance to the city centre has a higher correlation than the neighbourhood type. But for both holds: the nearer the centre the lower car ownership.

Appendix B.5 Accessibility

The accessibility is available on PC4 level for the year 2014 and represents the number of jobs that are accessible by (a combination of) bike and public transport. The PC4 level is a larger area than the level of investigation. There is assumed that the accessibility of the neighbourhood equals the accessibility of the overlapping PC4. Table 12-15 shows that there are multiple *buurten* that overlap a single PC4 area. As expected, the higher the accessibility by bike and public transport the lower car ownership.

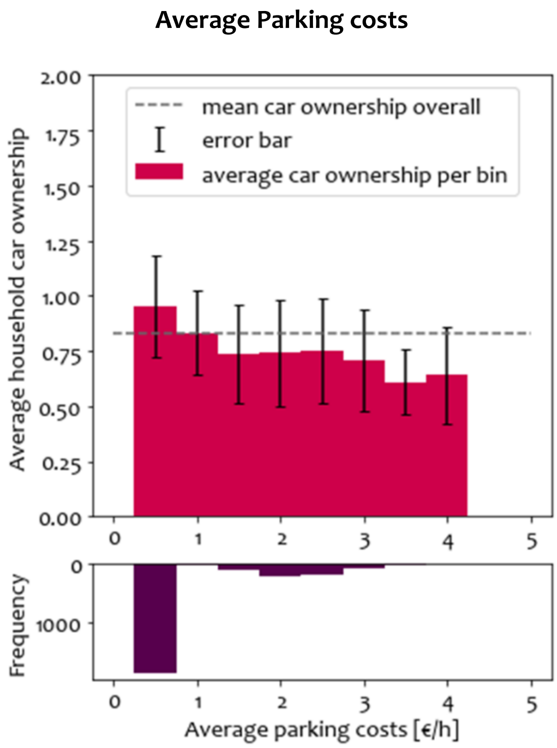
Table 12-15 Relation between accessibility and car ownership



Appendix B.6 Demand

The average parking costs represent the public parking policy in the neighbourhood. The more expensive public parking places, the lower the car ownership. Especially areas without pricing of public parking have on average higher car ownership. Since, residents may have parking places at their own property or they may have private garages, the public prices may not have an extreme effect on car ownership

Table 12-16 Relation between accessibility and car ownership



Corr: −0.38 , p-value = 0.00

Appendix B.7 Socio-demographics

The income of the residents is represented by the percentage of households with the lowest 40% of national income. The number of workers represents the percentage of residents that have an income. Both variables do not represent income directly but may be indicators of the wealth of the residents. There is a strong negative correlation between the percentage of households with lowest 40% of income and car ownership. So, the more people have an income of the lowest 40% of income, the lower car ownership. The negative correlation of number of workers and car ownership seems to represent underlying factors: it may for example represent the number of adults. Then, the indicator represents the ratio families and a high amount of families would therefore lead to high car ownership. These variables will be left out of the scope due to the uncertainty of representation.

Table 12-17 Relation between income and car ownership

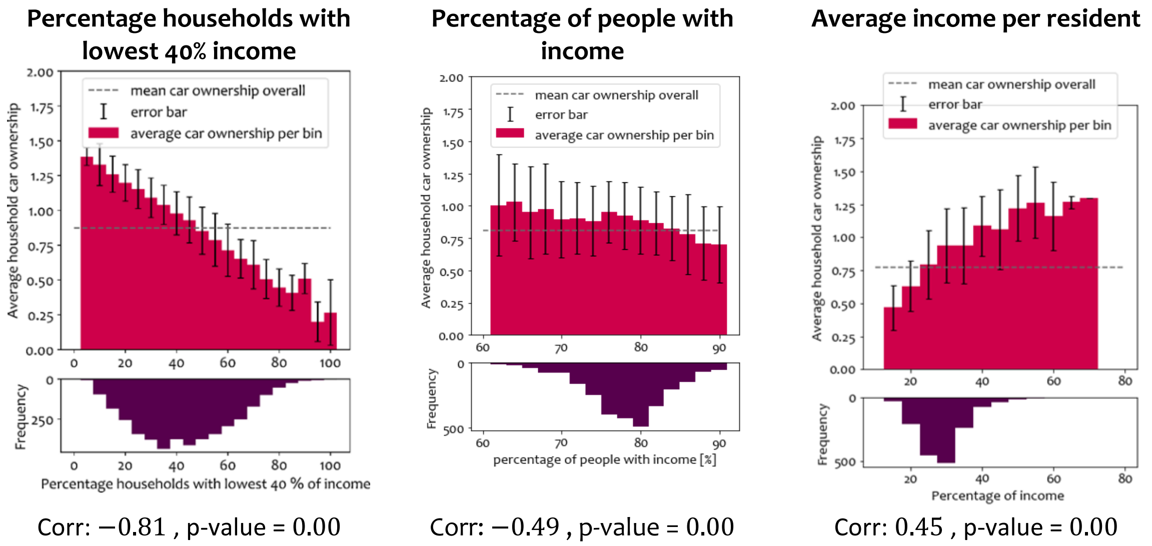
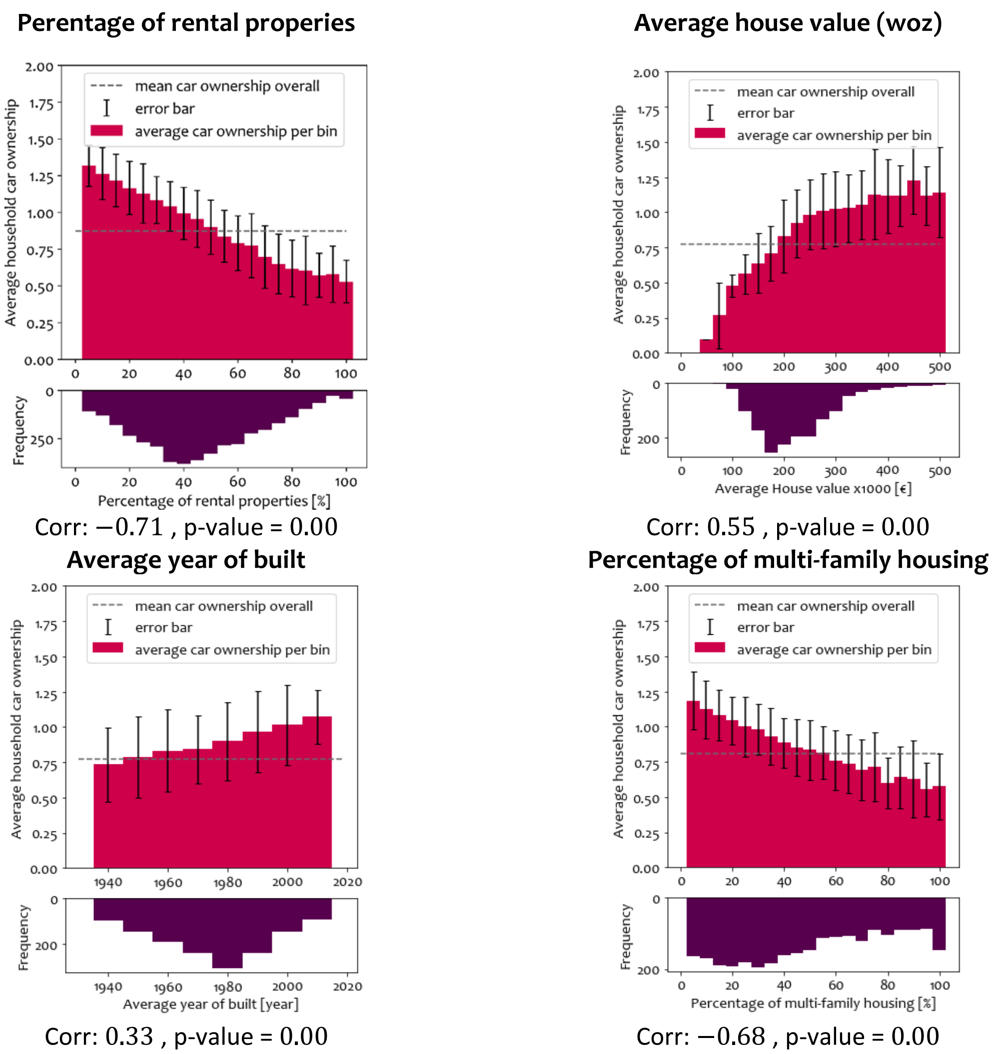


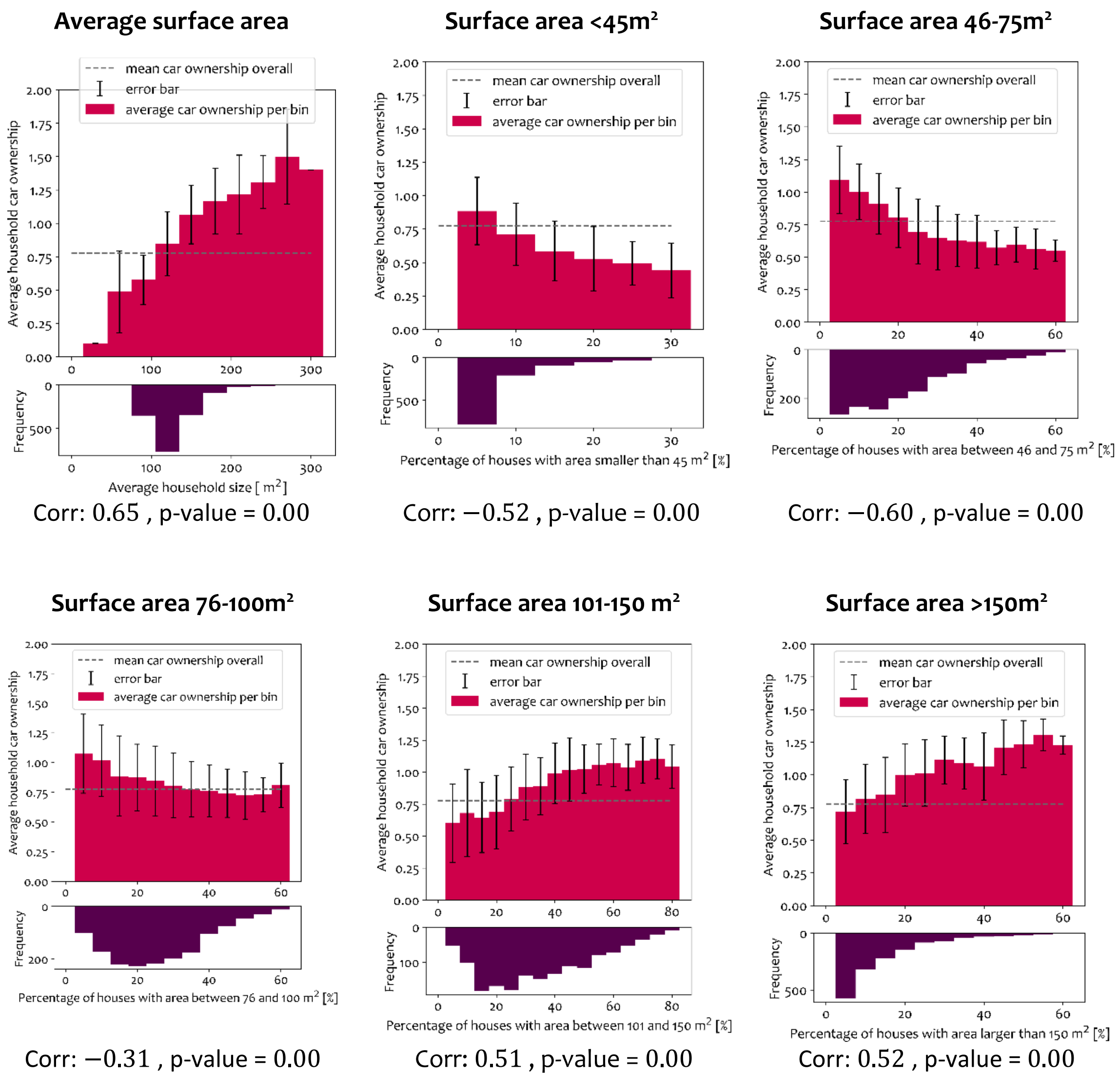
Table 12-18 Relation between types of residences and car ownership



The properties of the residents are represented by the percentage of rental properties, average house value and year of built. The percentage of rental properties has the highest correlation of the three. The higher the share of rental properties, the lower car ownership. The percentage of rental properties seems to have an identical relation with car ownership as the relation between the percentage of lowest 40% of income and car ownership. The correlation between percentage of rental properties and lowest 40% of income is significantly high: 0.87. Therefore, the percentage of lowest income may be a more representative variable than the percentage of rental properties.

The house value (in Dutch woz value) has a positive correlation: the higher the house value the higher car ownership. Again, the house value is significantly correlated with percentage of lower incomes. However, this time to a lesser extent: -0.64. Table 12-19 shows that the larger the surface are of the house the higher the average household car ownership. An even stronger effect is the percentage of multi-family housing. Multi-family housing stands for every property that shares the building with businesses or other residences. So, in general this variable represents the share of the apartments in the neighbourhood. When this percentage is low, the share of detached, semi-detached and terraced houses is high. Table 12-18 shows that the higher the share of apartments the lower car ownership.

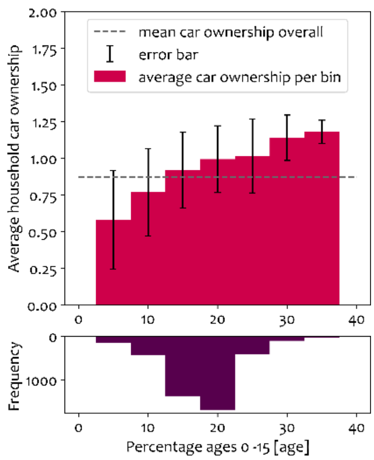
Table 12-19 Relation between average house size and car ownership



For the different available groups of ages, the relation between the percentage age group and average household car ownership is shown in Table 12-20.

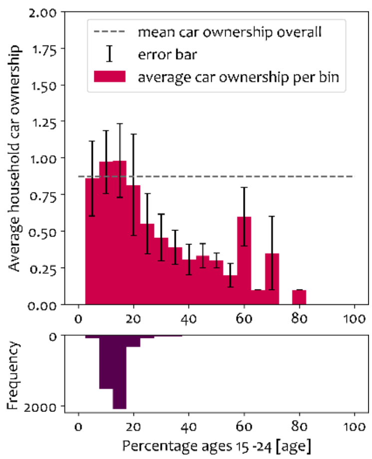
Table 12-20 Relation between age group and average household car ownership

Percentage ages 0-15



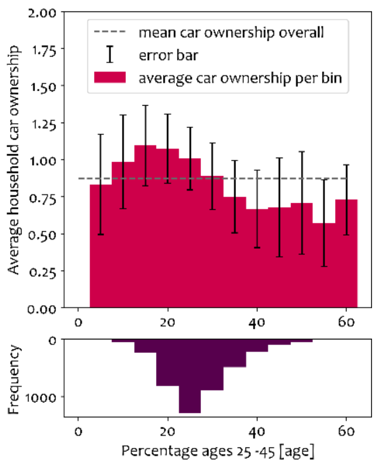
Corr: 0.37 , p-value = 0.00

Percentage ages 15-25



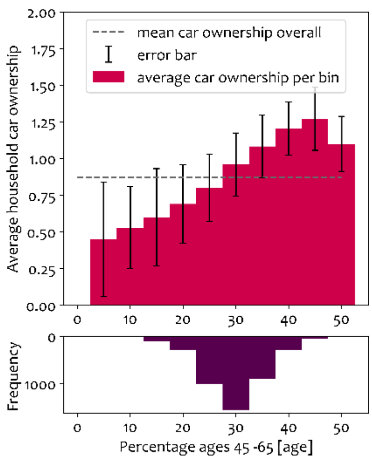
Corr: −0.36 , p-value = 0.00

Percentage ages 25-45



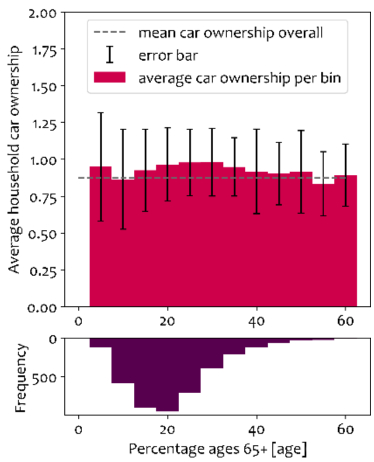
Corr: −0.45 , p-value = 0.00

Percentage ages 45-65



Corr: 0.57 , p-value = 0.00

Percentage ages 65+



Corr: 0.06 , p-value = 0.00

Appendix B.8 Intersection of independent variables

1.2 → Schiphol and low frequencies

Urbanisation level of		*Average car ownership*						*Frequency*					
	Municipality	1	1	1	2	2	2	1	1	1	2	2	2
	Buurt	1	2	3	1	2	3	1	2	3	1	2	3
1	Cathedral	0.5	0.8	1.2	0.9	1.0	1.2	64	12	1	7	12	5
2	Mega	0.6	0.8	1.0	0.6	0.9	1.0	147	46	10	74	58	19
3	Plus	0.7	0.9	1.0	0.8	0.9	1.1	103	36	6	180	262	83
4	Basis	0.7	1.0	1.1	0.8	1.0	1.1	267	112	51	188	667	294
5	Stop	0.7	1.0	1.1	0.7	1.0	1.1	7	14	8	32	113	63

Appendix C Linear Regression results (Cross-sectional analysis)

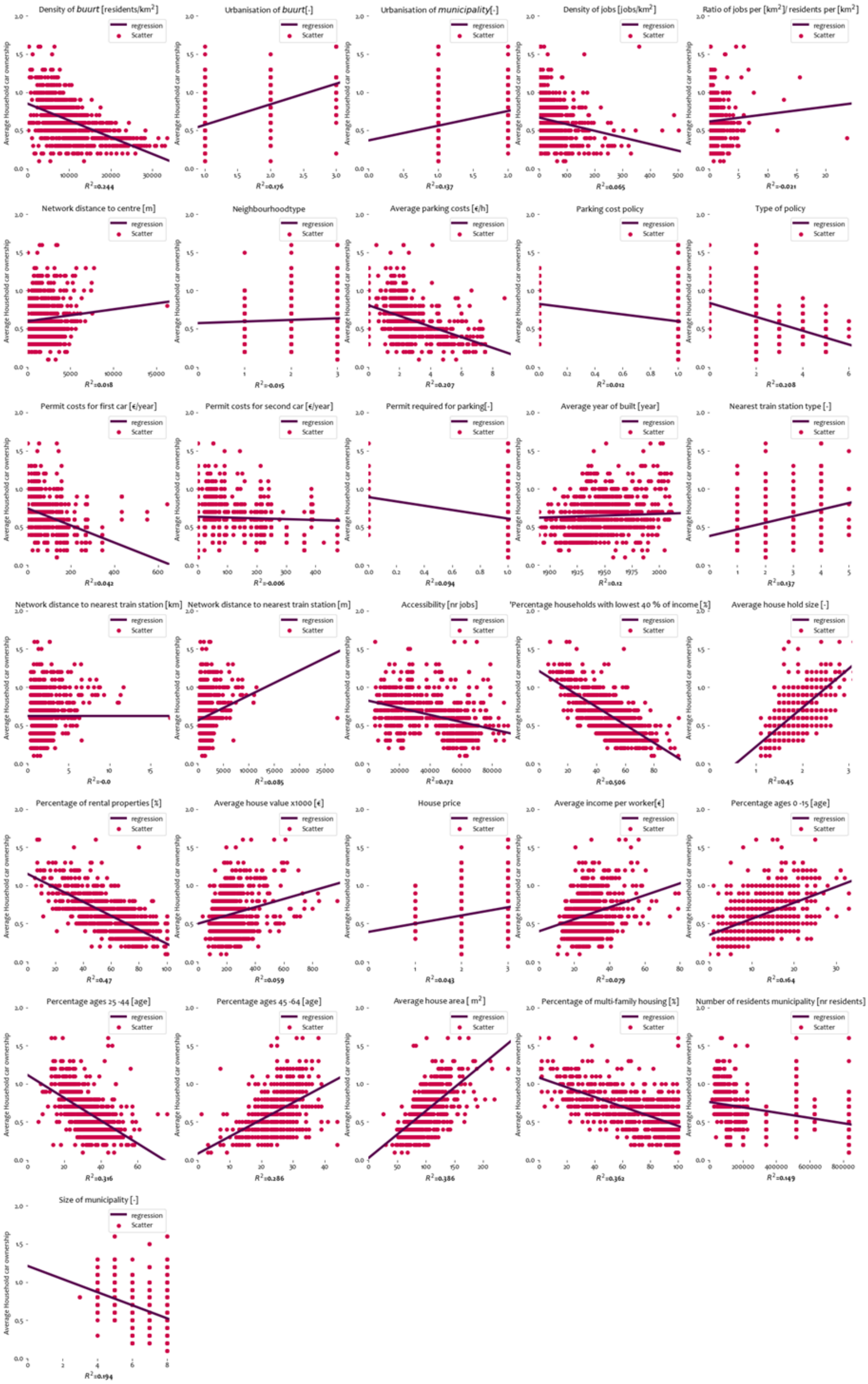


Figure 12-9 Single linear regression (OLS) results with car ownership as dependent variable. Given is the coefficient of determination (R^2)

Appendix D Key figures

CROW presents only the minimum and maximum car ownership as a bandwidth; the bar plots are the mean of the min and the max values. The error bar represents the bandwidth: the min and max. In this case the error bar represents the bandwidth and the

However, the bar plots are not exact representations of the actual CROW key figures, they are averages of every record in the tables that corresponds to the value. For example, Social rent occurs only for houses, not for apartments, so the number of social rent seems higher than normal rent. While Rent was only available for apartments. Another example is the price level is for example only applied for apartments: which is explaining the lower number for expensive dwellings than for detached houses.

So, the actual values of the bar plots should not be taken into account; in contrast, the directions of increase in car ownership are more comprehensible. The largest differences within the variable are for the different house types. The on average large the house type, the higher car ownership.

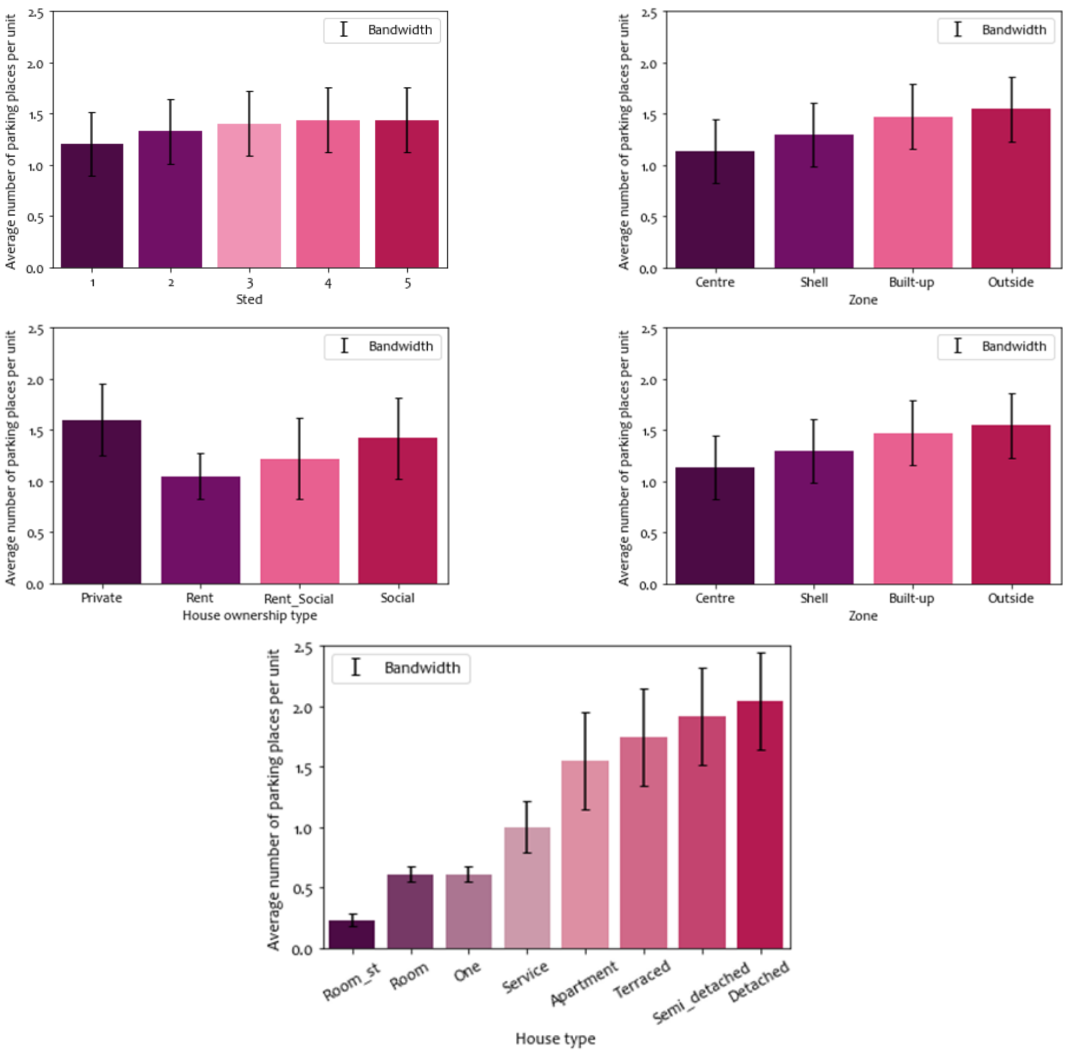


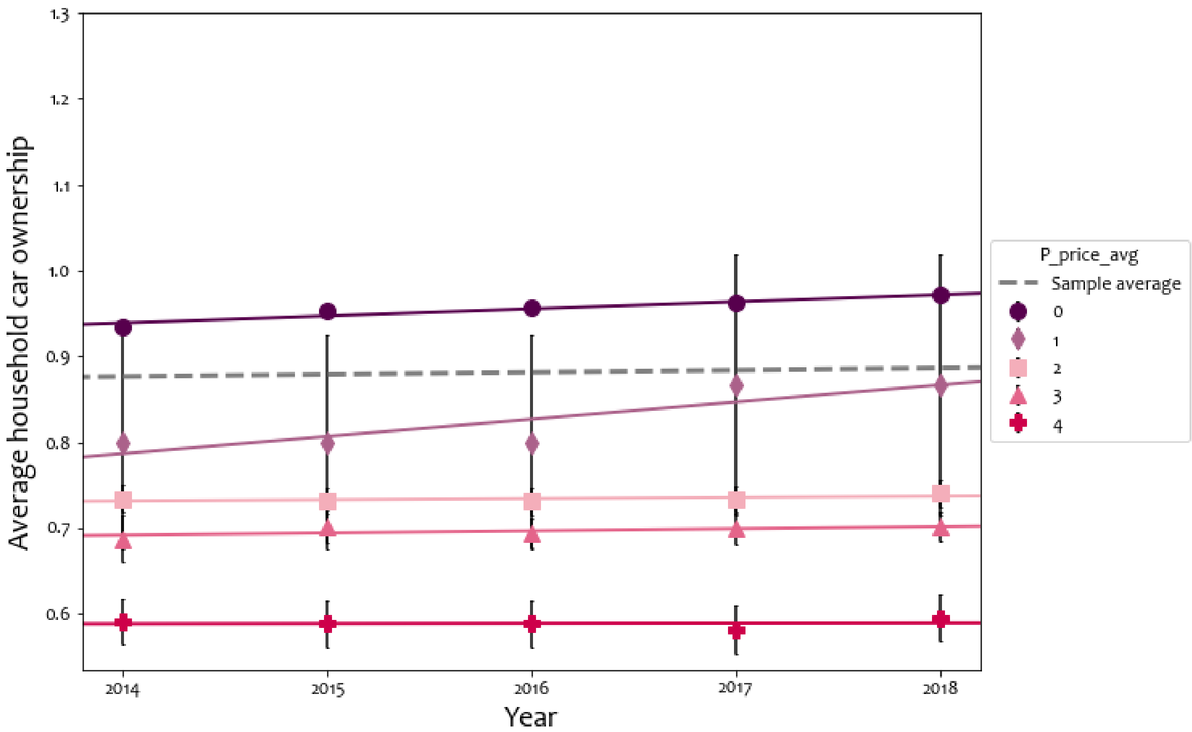
Figure 12-10 CROW Key figures in bar plots

Table 12-21 Combinations of variables in CROW guidelines

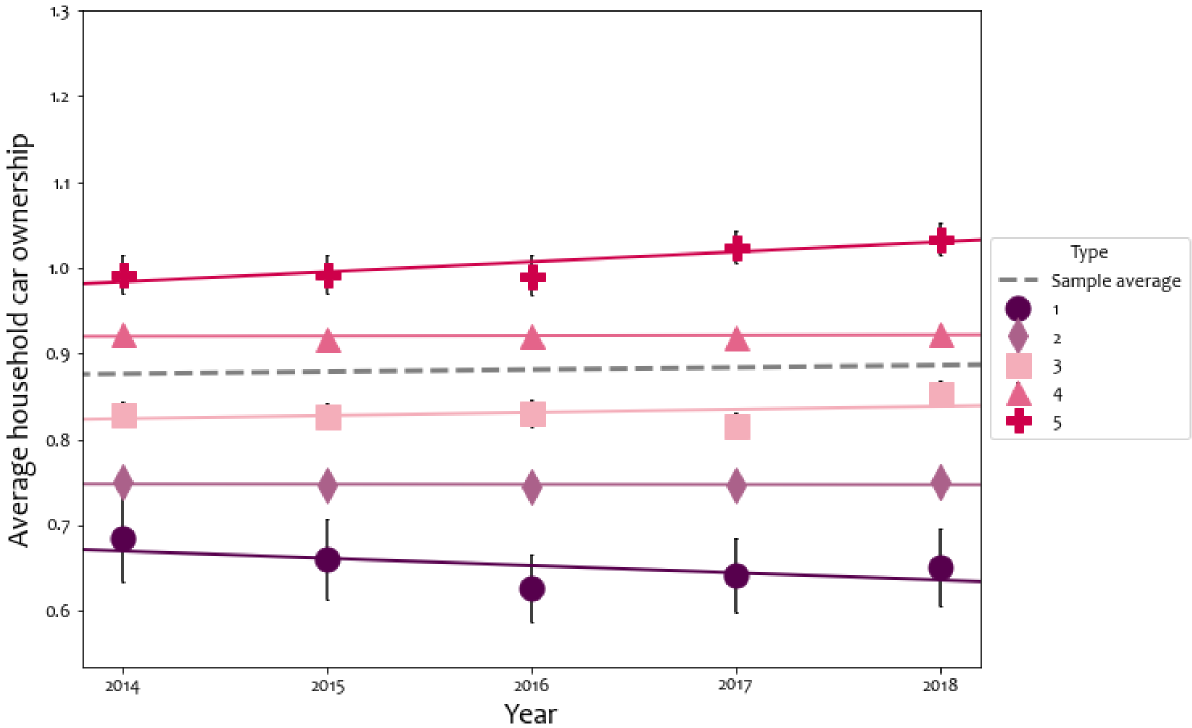
Ownership	House	House Type	Price	Rent type	Student
Private	House	Detached			
Private	House	Semi-Detached			
Private	House	Terraced			
Private	Apartment		Expensive		
Private	Apartment		Mid		
Private	Apartment		Cheap		
Rent	House			Free sector	
Rent	House			Social sector	
Rent	Apartment		Expensive	Free sector	
Rent	Apartment		Mid & Cheap	Free sector and Social sector	
Room Rent	Room				Nonstudent
Room Rent	Room				Student
Nursing home	Nursing home				
Private	One person				

Appendix E Aggregated longitudinal study

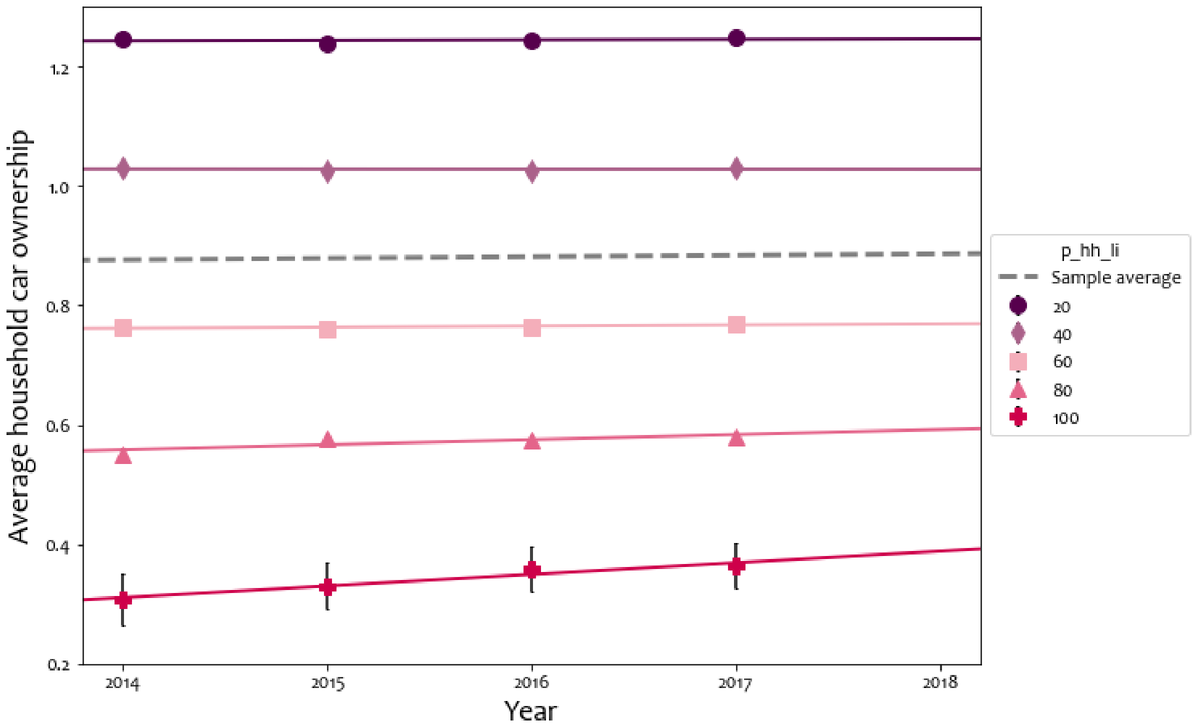
Parking costs



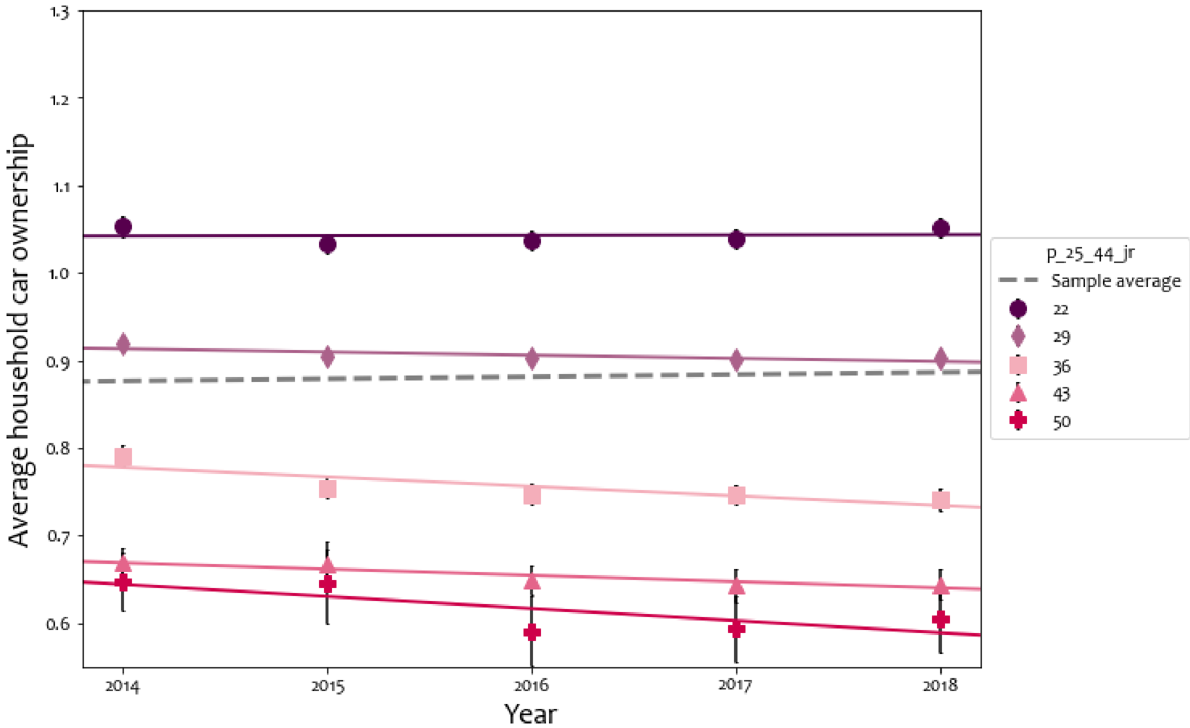
Train station type



Percentage of people with 40% lowest income



Percentage of people between 25 and 44



Percentage of people between 45 and 64