Effects of e-mobility hubs in residential areas on car use and ownership

Stated choice experiments in the context of Dutch cities

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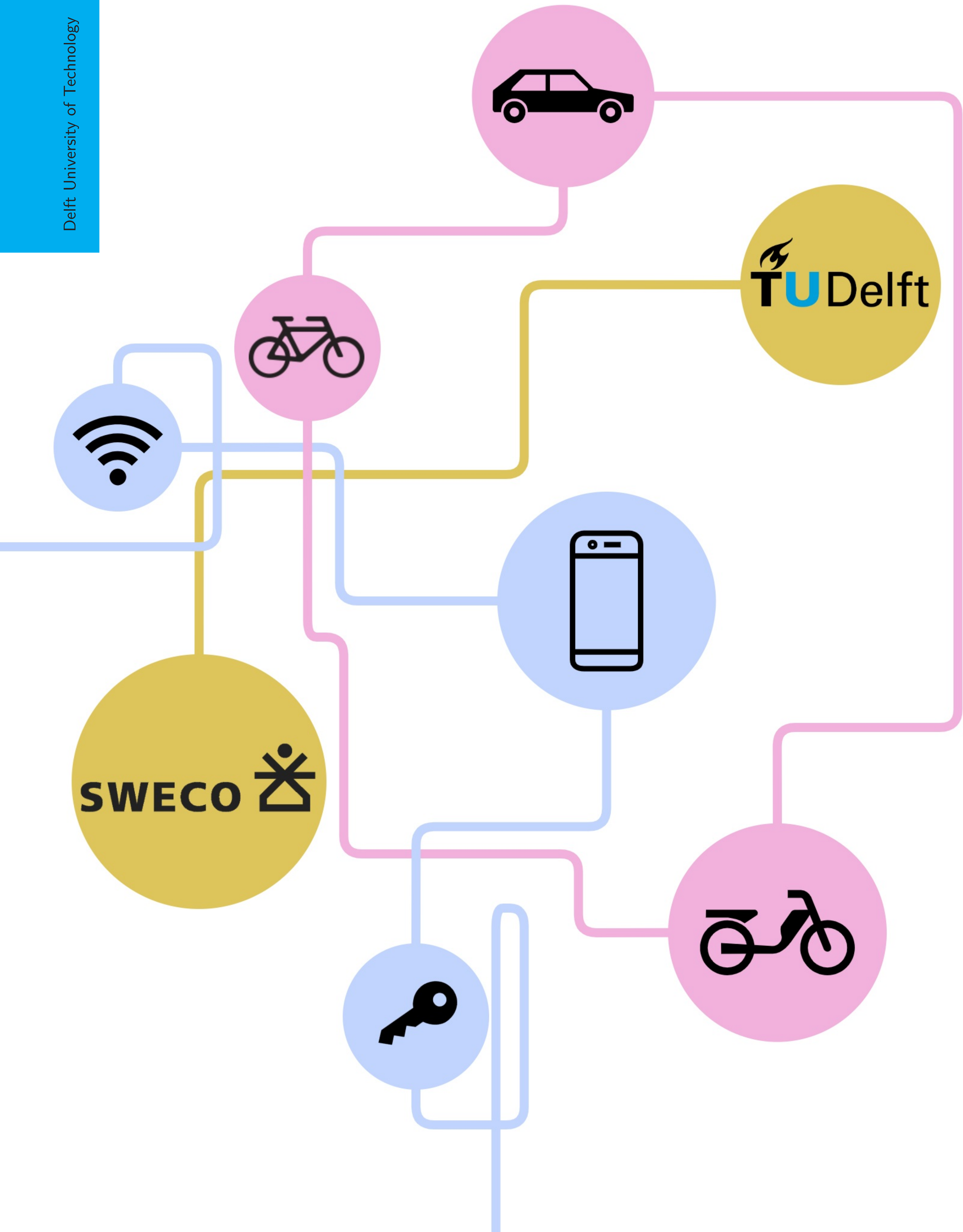

Effects of e-mobility hubs in residential areas on car use and ownership: Stated choice experiments in the context of Dutch cities

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PREFACE AND ACKNOWLEDGEMENTS

This graduation research was conducted as the final part of the MSc programme in Transport, Infrastructure and Logistics at Delft University of Technology. This thesis is the final part of my studies and student life. In the final phase, I discovered my curiosity for the future of cities and my interest in the choice behaviour of people. These interests resulted in my thesis research, in which I researched the willingness to use shared mobility services offered in mobility hubs in order to contribute to a more liveable city and a more sustainable transport system.

I would like to express my gratitude to my graduation committee for the critical but positive feedback that has resulted in this study of which I am proud. First of all, I want to express my sincere gratitude to Victor Knoop as chairman of my committee. I would like to express my sincerest gratitude to Gonçalo Correia for motivating and supervising me. The intensive meetings kept me on my toes. I was very impressed by his commitment and patience throughout my research. I also want to express my sincere gratitude to Jan Anne Annema for his perspectives and guidance throughout my research.

Furthermore, I would like to express my sincerest gratitude to my supervisor Ross Ruiter. Conducting research on your own for months can be challenging, and Ross provided me with excellent guidance. I was impressed by his helpfulness and comments that led to interesting discussions and insights. I am also grateful to Willem Scheper and Jeroen Quee for their guidance and knowledge.

Ever since I can remember, I knew that I wanted to be an engineer, just like my father and grandfather. I deeply regret that my grandfather could not enjoy this moment with me. Nevertheless, I am grateful to both gentlemen for piquing my interest in technology. I would also like to thank my mother, sister and my friends for always supporting me in everything I do.

Mathijs Céderic Franken
Amsterdam, April 2021

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Executive summary

In Dutch cities, car use and car ownership is too high. Offering shared mobility services might lead to a reduction in car use and private car ownership. Dutch municipalities are interested in offering shared mobility services at fixed locations, the so-called mobility hubs. However, the actual effects of mobility hubs on car use and car ownership are not known. Therefore, the purpose of this thesis was to examine the effects of mobility hubs on car use and car ownership. Besides the academic relevance, it is also important for Dutch municipalities to know the potential impact of mobility hubs. Local governments can focus on the development of mobility hubs in order to initiate a transition to a cleaner and more efficient transport system. To explore the unexplored effects of mobility hubs, the following main research question was formulated:

What factors explain people's willingness to use shared mobility alternatives in mobility hubs for trips and the willingness to give up the least used private car, and to what extent?

To answer this question, a survey was conducted among Randstad residents. To examine the effects of mobility hubs on car use and car ownership, two stated choice experiments were included in the survey. The first experiment focused on the mode choice between the private car and shared mobility services for commuting trips, while the second experiment focused on the mode choice between keeping or giving up the private car and use mobility hubs for all trips. The attributes included in the experiments were related to trip time, travel costs and preference for shared mobility modes. The socio-demographic characteristics were collected through general questions in the survey

In the Netherlands, the majority of shared mobility services found in cities are already electrically powered. In view of the future where electric transport is likely to be the norm, this research focused on electrically powered shared mobility modes offered in mobility hubs. Based on the presence in the Dutch transport system, it was assumed that in mobility hubs shared e-cars, shared e-mopeds and shared e-bikes are offered. Due to the interest from municipalities and the problems related to private cars, this research focused on all types of residential environments in the Randstad. This concerned city centres, suburban areas and rural areas.

The survey was distributed both online and offline among Randstad residents and resulted in 574 respondents which were used for the data analysis. 495 respondents participated in the first mode choice experiment, compared to all 574 respondents of the whole survey and of the second mode choice experiment.

The sample of respondents consisted mainly of inhabitants of South Holland, North Holland and Utrecht. The respondents were mainly young people with a high level of education and income. Almost half of the respondents had ever used a shared bike, while almost 16% had used a shared car, which is the least. Respondents were also most familiar with the shared car, almost 2% had never heard of it, while almost 8% had never heard of the shared moped. Nevertheless, the shared moped car was rated best, followed by the shared car and the shared bike was rated worst.

Based on the data from the respondents and the experiments, extended multinomial logit models were used to estimate the parameters. The results of the discrete choice models for the two stated choice experiments on the mode choice provided interesting new insights.

In the first mode choice experiment, a positive preference for the use of the shared e-car over the private car for commuting trips was found. However, the decision to opt for a shared e-car for commuting trips depends on various factors. Moreover, residents of a city centre (and suburban area) are more likely to use a shared e-car than residents of a rural area for short distances of 7.5 and 22.5 kilometer to work. The sensitivity for the trip costs is higher for the shared e-car than for the shared e-moped and e-bike. For distances of 7.5 and 22.5 kilometres to work, sensitivity to walking times is greatest for the shared e-bike, followed by the shared e-moped. While the results showed that the walking times of the private car are almost equally sensitive to the walking times of the shared e-car. For distances of 45 and 75 kilometres to work, the sensitivity to walking times for the private car and the shared e-car is almost equal.

In the second mode choice experiment, there appeared to be a positive preference for the mobility hub over the private car, however, the decision to give up the private car depends on several factors. Respondents with a low monthly car use of 500 kilometre and who live in a household with one or two cars are more likely to give up the least used car than respondents who live in a household with three cars or more. Moreover, respondents with a monthly car use of 500 and 1500 kilometre and who live in a city centre are more likely to give up the private car than respondents who live in a rural area. The sensitivity to walking times from household to mobility hub is higher than to a private car. The sensitivity to operating costs of the shared e-car is higher than those of the shared e-moped and e-bike. Car owners who are willing to give up the least used car prefer full use of the shared e-car as a substitute for the private car.

Since the impact of the various factors on car use and car ownership was determined, the effect on car use and car ownership could be determined for the focus areas. These focus areas were a city centre, a suburban area and a rural area in the Randstad in the Netherlands. Based on the objectives of Dutch municipalities, strategies were examined to what extent these strategies affect private car use and car ownership. This research considered three types of mobility hub grid plans and pricing strategies.

The willingness to use shared mobility services for commuting trips is slightly greater in a city centre and suburban area than in a rural area. Therefore, the reduction in private car use in the city centre and suburban area is slightly greater than in the rural area. Since the preference for the use of the shared e-car is high, mobility hubs do not greatly reduce the number of car movements. The willingness to give up the least used car is highest for residents of the city centre, followed by those of the suburban area and is lowest in those of the rural area. The effects on the number of cars per household in the district are greatest in the city centre, followed by the suburban area and by far the least in the rural area. For a reduction in car use and car ownership, the density of mobility hubs is an important factor. A higher mobility hub density increases the willingness to use shared mobility services and also increases the willingness to give up the least used private car. Moreover, the operating costs of the shared mobility services are also important factors. The reduction of operating costs increases the willingness to use shared mobility services for commuting trips, and also increases the willingness to give up the least used private car.

This research has contributed to addressing a part of the research gap of the unexplored decision-making process with regard to the acceptance of mobility hubs. The research revealed that the potential of mobility hubs on car use and car ownership differs per type of residential area. The walking times to a mobility hub and private car are important factors determining the willingness to use shared mobility services and the willingness to give up the private car. On top of that, the operating costs of the shared mobility services are important factors on the willingness to use the services as well. Therefore, in order to stimulate a transition to reduced car use and car ownership, it is important to decide on the mobility hub density for a residential area and operating costs for the shared mobility services.

1 Introduction

Over the past few decades, the growth of the world's population has exploded. Next to this exorbitant growth, many countries also experience urbanization of the areas around and in cities. This phenomenon is also happening in the Netherlands. The population in the Netherlands is growing strongly, it is growing so fast that with the current growth in 20 years almost 20 million people will live in the Netherlands [van der Heijden, 2020]. Simultaneously, half of this growth will take place in the Randstad region, while a shrinkage is visible in some rural areas [APPM, 2020, CBS, 2018a]. The Randstad primarily consists of the four largest Dutch cities and the surrounding areas. The population in the Randstad will grow by 15% by 2030, putting pressure on the living environment and accessibility [CBS, 2016a].

Car ownership in the Netherlands is huge among all age groups [Statline, 2017]. While these private passenger cars are parked 95% of the total life time, and are seldom used more than 10% of their lifetime [BPD, 2018]. The private car uses a lot of space compared to other modes [Natuur & Mileu, 2020]. Since parked cars take up a lot of space, there is less space for green spaces and the quality of life in cities is deteriorated [Gemeente Amsterdam, 2019]. In addition, there are environmental considerations for the entire country that must be achieved within a limited time. Transport using fossil fuel-powered modes is harmful to both the health of the people in the city and the environment, due to emissions of CO2, nitrogen and fine dust, among other things [Natuur & Mileu, 2020]. As a result, it is important to reduce the ownership and use of the car in the Netherlands and make more use of sustainable transport options [Natuur & Mileu, 2020].

Problems associated with private cars can be found in many Dutch cities, from the city centre to the suburbs to the more rural areas, and as a result of strong urbanization, municipalities will face greater mobility challenges [CROW, 2008]. For the future of Dutch cities, strategies are developed to ensure that the quality of life and accessibility will be maintained in the years to come. These strategies are aimed at reducing driving and parked cars, and improving public space with more clean and active travel [Gemeente Amsterdam, 2019]. Shared mobility offered in mobility hubs are among the key elements of these strategies [Kwantes et al., 2019]. Mobility hubs are locations where shared mobility, such as electric cars, electric mopeds and electric bicycles, can be offered. Shared mobility and mobility hubs are emerging as an alternative to the private car, but the impact on car use and car ownership is unknown.

The amount of scientific research on the use of shared mobility services offered in mobility hubs is increasing rapidly. Most of these studies are based on stated choice experiments, while the number of pilot studies is quite limited, see section 2.1. The adoption rate in cities where pilots of shared mobility services have been conducted is very low, see section 2.1. These pilot studies have been conducted in several cities in the world and there are no results known from pilot studies in the Netherlands. However, there are studies for Dutch cities based on stated choice experiments. According to Caiati et al., Dutch people are not very willing to use shared mobility services in the long term and would rather try it once in a while. In the current literature only studies are available that show effects of one type of shared mobility service, either shared e-car, e-moped or e-bike, on car use or ownership, see section 2.1. The impact of the combination of the three types of shared mobility services, as will be offered in a mobility hub, on car use and car ownership has not been studied yet, see section 2.1. Hence it is unknown how the current transport system will be influenced by the advent of mobility hubs. Therefore, insight needs to be gained into the decision-making process of Dutch car owners regarding the services offered in mobility hubs. That is what this research will focus on.

1.1. SCOPE AND GOAL

There are many different definitions for mobility hubs. Due to the wide variety of definitions of mobility hubs an appropriate definition of a mobility hub is required for this research. The definition of a mobility hub is the result of a combination of other definitions of mobility hubs [Advier, 2019, Hely, 2020, Share North, 2017].

A mobility hub is a multi-modal mobility hub where a combination of different shared mobility services are offered. These services include shared e-cars, e-mopeds and e-bikes. Facilities that can be offered at a mobility hub are not included in this study. This makes a mobility hub simply a parking facility where parking spaces are only available for shared mobility modes.

This research focuses on mobility hubs where only electrically powered alternatives are offered. In the Netherlands, shared mobility services are already mainly electrically powered, and electrically powered vehicles are expected to become more common in the coming years, see chapter 2. Since vehicles with fossil fuels have higher emissions than electrically powered cars, offering electric shared mobility alternatives would contribute to a transition to a more liveable city [Natuur & Mileu, 2020]. Moreover, facilitating shared mobility services is one of the approaches to make a city or village more liveable and sustainable [Gemeente Amsterdam, 2019]. For the sake of simplicity, this research considers a mobility hub as a location where shared mobility modes are offered without other facilities at this location. The shared mobility systems are station-based, which means that the modes have to be picked up and returned to a mobility hub. The shared mobility alternatives can be used for a single trip, i.e. from mobility hub A to mobility hub B. Regardless of the location to which the shared alternative is picked up or taken to. In this research it is assumed that the different shared mobility alternatives are always available. In other words, for the three shared modes it is assumed that the fleetsize is infinitely large.

There is interest in mobility hubs from various municipalities in the Randstad [City Deal, 2018]. Since shared mobility might reduce car-related problems [Gemeente Amsterdam, 2019, Utrecht, 2021]. The pressure on infrastructure and the parking problems can be found in Dutch cities, from the centre to the suburbs to the more rural areas [CROW, 2008]. Due to the interest from municipalities and the problems related to private cars, this research focuses on all types of residential environments in the Randstad. This concerns city centres, suburban areas, hinterlands and rural areas, see section 7.2. The first two residential areas are considered city areas, and the last two non-city areas respectively.

The focus of this research is on people in the Netherlands with a private car, and therefore people with a company car and private lease car are excluded. In the majority of cases, people with a company car cannot choose to give up the car, or use a shared vehicle for work-related trips. Furthermore, eighty-eight percent of the passenger cars in the Netherlands are privately owned, which means that only a small proportion of the cars in the Netherlands are lease-cars [CBS, 2019b].

The effects of shared mobility services offered in mobility hubs on private car use and private car ownership are not known, hence this research focuses on both aspects. Shared mobility services mainly have the potential to replace the least used private car, therefore this research focuses on the effect on car use and car ownership of the least used private car, see section 2.1. This research focuses on the modal shift effects of the advent of mobility hubs in residential areas on commuting trips in order to estimate the effects on private car use, the motivation for which is further explained in section 2.2. Insight into the willingness to use shared mobility services for commuting trips helps to obtain a more profound idea of the general willingness of people to make use of shared mobility services. In this research the modal shift effects for commuting trips are called the short-term effects of mobility hubs. This research also focuses on the long-term effects of mobility hubs. The long-term effects relate to private car ownership. These effects focus on the willingness to give up the least used private car and use the shared mobility services of the mobility hubs for all the trips that would have been made with the private car. Insight into both short-term and long-term effects can be used to effectively reduce car use and car ownership in municipalities.

While this research is academically relevant, it is also relevant from a social point of view. The outcome of this research is relevant and useful for transport engineering companies. This research aims at exploring the decision-making process related to the acceptance and use of mobility hubs. The potential of mobility hubs to replace the private cars is in line with the desire of Dutch municipalities to reduce car use and car ownership of residents in these cities. Local governments can focus on the development of mobility hubs in order to initiate a transition to a cleaner and more efficient transport system.

From the indicated and considered research gap regarding the as yet unexplored decision-making process with regard to the acceptance of mobility hubs, the goal of this research is:

To explore and measure the factors that influence people' s willingness to use shared mobility alternatives offered in mobility hubs for trips and the willingness to give up the least used car.

Since there is no operational network of mobility hubs at the moment, the effects on car use and car ownership are unknown. Stated choice experiments can provide insight into the effects of mobility hubs for future situations, see section 3.2. The objective of this research is to gain a more comprehensive insight into the effects of mobility hubs on car use and car ownership. The aim is not to predict the exact demand for shared mobility services in the future. Therefore, this research concerns an exploratory research.

1.2. RESEARCH QUESTIONS

Based on the aforementioned knowledge gap and the scope of this research, the main research question is:

What factors explain people's willingness to use shared mobility alternatives in mobility hubs for trips and the willingness to give up the least used private car, and to what extent?

In order to eventually answer the research question, the following sub research questions were formulated:

1. Which factors influence mode choice and car ownership according to literature?
2. What factors of mobility hubs are most relevant that might influence mode choice and car ownership?
3. To what extent do these factors influence the mode choice and car ownership?
4. What are the effects of mobility hubs on car use and car ownership in different residential areas of the Netherlands?

1.3. RESEARCH STRUCTURE

The research consists of four parts, namely conceptualization, data collection, data analysis and models estimation and scenario analyses. Figure 1.1 shows the structure of the study with the different parts.

CONCEPTUALIZATION

First, literature is used to theoretically and scientifically underpin the various concepts in this research. Furthermore, literature is reviewed in order to determine mode choice factors, factors related to shared mobility services, and factors related to mobility hubs.

A conceptual framework is created using the mode choice factors identified in the literature and discussions with experts. Experts in the field of shared mobility are consulted to identify the most relevant factors that can influence car use and car ownership. The result is a conceptual framework, which is used for the design of the stated choice experiments.

DATA COLLECTION

To examine the effects of mobility hubs on car use and car ownership, two stated choice experiments are conducted. Since mobility hubs do not exist, stated choice experiments can provide insight into the effects of mobility hubs for future situations in which they actually exist. The effect of factors, identified in the conceptual framework, on the decision-making process of people can be measured using stated choice experiments. The first experiment deals with the short-term effects of mobility hubs, which gives insight into the effects on private car use. While the second experiment deals with the long-term effects, providing insight into the effects on car ownership. Chapter 5, further explains how the stated choice experiment was designed.

DATA ANALYSIS & MODELS ESTIMATION

The data of the survey including the choice data are analysed using two techniques. The descriptive statistics describe the characteristics of the sample and the choice distributions in the two experiments. Discrete choice modelling is used to gain insights into the impact of the factors on people's willingness to use mobility hubs and give up the private car.

SCENARIO ANALYSES

In the end, the data and models are used to gain insight into the effects of mobility hubs for three focus areas in the Netherlands.It concerns three locations where problems with car use and car ownership arise. For these three areas, the effects on car use and car ownership are determined using the results of the two models.

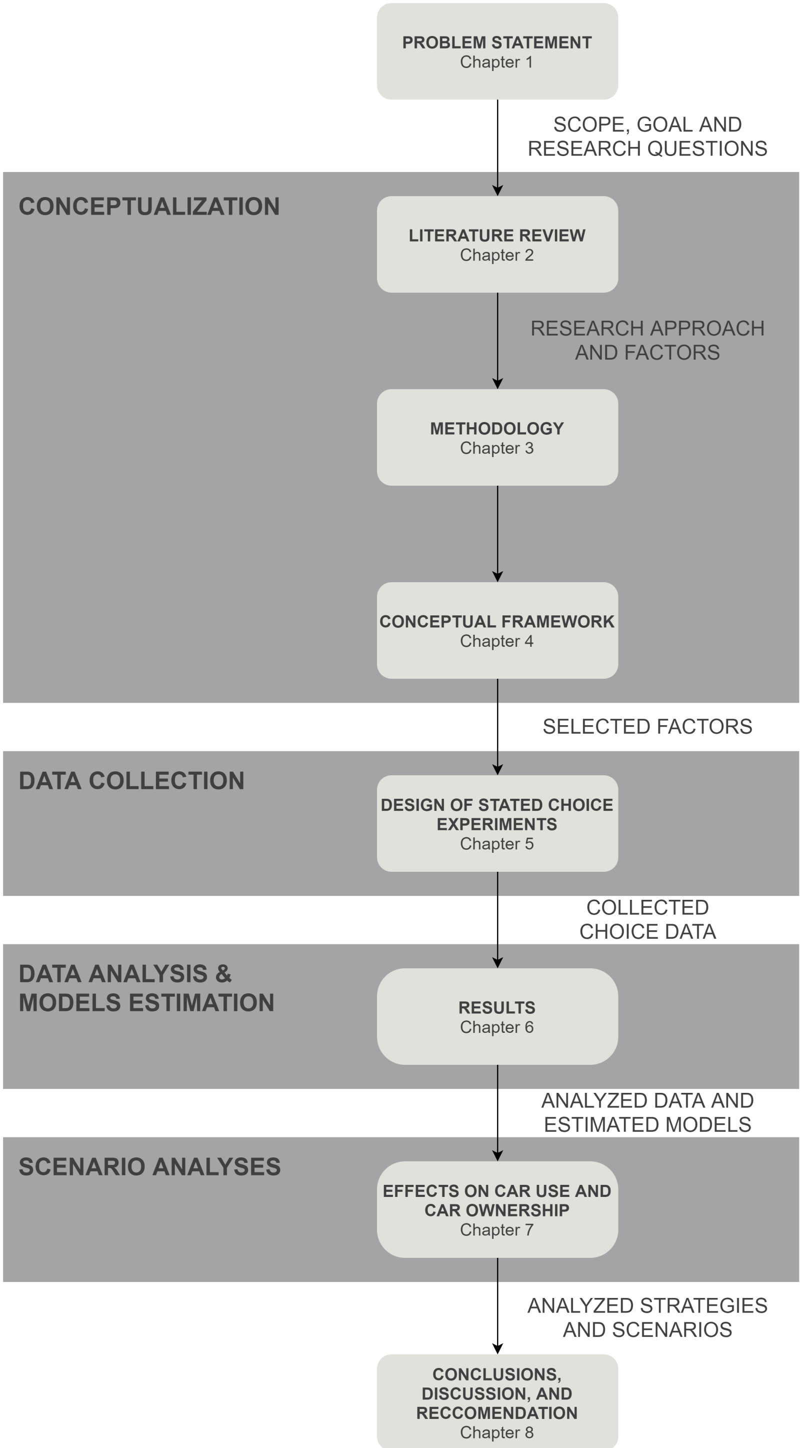


Figure 1.1: Research methodology overview.

2

Literature review

This chapter discusses and underpins the knowledge gap, the different concepts and the factors that influence mode choice. First, section 2.1 discusses the knowledge gap in the literature on shared mobility services and mobility hubs. Next, section 2.2 and 2.3 elaborate on the different concepts presented in the introduction. Finally, section 2.4 discusses the factors that might influence the mode choice process in the short and long term. section 2.5, summarises the knowledge gap and the application of the literature review to the rest of the research.

2.1. Mobility hub pilots and experiments

The number of studies related to shared mobility services is growing rapidly. While there are currently few studies on mobility hubs. Since this research focuses on mobility hubs, which is a location where various shared mobility services and facilities come together, the focus here is on mobility hub pilots and experiments.

One of the first pilot projects, which included several shared mobility services, took place in Gothenburg, Sweden during 2013 and 2014. It showed that car owners drove less with their private cars and used more active modes and public transport [Strömberg et al., 2018]. Moreover, people living in the city centre were more likely to use shared cars than those living in suburban areas. Another shared mobility experiment was conducted in Vienna, Austria from 2014 to 2015 [Fioreze et al., 2019]. Of all the participants in the experiment, only 30 percent used the services on a weekly basis, and only 6 percent on a daily basis. However, after the experiment, 50 percent of the respondents reported that their travel patterns had changed, and 20 percent indicated that they used their private cars less.

Most studies regarding mobility hubs are based on stated choice experiments. According to these studies with stated choice experiments, the adoption rate for shared mobility services offered in a mobility hub is low. Stated choice experiments performed in the Netherlands show that respondents are not very willing to use shared mobility services [Dieten, 2015]. Moreover, respondents were extremely sensitive to the monthly prices to be paid for the services [Caiati et al., 2020]. A study conducted in Den Bosch, the Netherlands, shows that city centre residents are not willing to use shared mobility services in the long term [Fioreze et al., 2019]. However, they are interested in exploring and trying it out. Furthermore, the study shows that the willingness to use the shared mobility services is higher among people who do not value car ownership and car use highly than among people who value them. A recent study in the UK shows that the adoption rate is very low [Ho et al., 2020]. The people who wanted to use the shared mobility services had mainly economic reasons for doing so. Moreover, the majority (almost 50%) continued to use their own car. Since car use and car ownership in the Netherlands is very high, the Dutch government wants to change this, see section 2.2. The Dutch government has started seven different shared mobility pilots in the Netherlands. In these pilots, the government wants to test the use of shared mobility services in different contexts [IenW, 2019]. In this way the Ministry wants to get a better idea of where the potential lies for offering shared mobility services in the Netherlands in order to reduce car use and car ownership. As the duration of these pilots is two years, no results are available at the time of this research. A study conducted by De Vliet [2019], shows that besides the low adoption rate of shared mobility, there actually is potential to change people's travel behaviour and car ownership. However, shared mobility could only replace the second or the least used car [De Vliet, 2019, de Vos et al., 2019]. Households with several cars would be more willing to use shared mobility services than households with low car ownership [Ho et al., 2020]. Households with several cars will therefore be the potential group that will use shared mobility services.

2.2. CURRENT SITUATION AND PROBLEMS REGARDING PRIVATE CARS

This research focuses on Dutch car owners. In order to underpin the scope of this research, background information is needed as to why the focus is on private cars and different areas. Section 2.2 focuses on car ownership in the Netherlands. After which in section 2.2.2 passenger mobility is discussed. Section 2.2.3 discusses the focus for the different areas. Finally, section 2.2.4 discusses the spatial problems associated with private cars.

2.2.1. CAR OWNERSHIP

Car ownership has been growing strongly in recent years. It is growing even faster than the population of 18 years and over. In the beginning of 2020 there were almost 8.7 million passenger cars in the Netherlands, of which more than 7.6 million are privately owned [CBS, 2019b]. In 2020, compared to five years ago, 7.5% more cars owned by private individuals and 19.1% more cars registered in the name of a company [CBS, 2020b]. Company lease cars are not included in this study since it is not always possible to give up a company car for individuals. The number of private lease cars in the total Dutch vehicle fleet is 2% [VNA, 2020]. Due to the low share of private lease cars, private lease cars are not included in this research. Since nearly 90 percent of all cars in the Netherlands are privately owned, this study focuses only on car use and car ownership of private cars. Car ownership in the Netherlands is high in every age group [Statline, 2017]. Moreover, in every age group, car ownership is higher among men than among women. This study therefore focuses on both male and female car owners aged 18 and older.

In the Netherlands, the share of fossil fuel powered cars accounts for 97% of the total Dutch vehicle fleet in 2019. The proportion of fossil fuel cars is roughly stable over the last ten years. The number of plug-in hybrids and fully electric cars has been growing rapidly over the same period [IenW, 2020]. Both petrol and diesel cars emit much more CO2 per kilometre travelled per passenger than other types of transport [IenW, 2020, Natuur & Mileu, 2020]. Especially if fossil-fuel cars are compared to hybrid or electric cars. The same applies to a petrol moped and an electric moped. Since the environmental situation is a hot topic in recent decades, it is important to move away from fossil fuel powered transport modes and switch to sustainable powered vehicles.

2.2.2. PASSENGER MOBILITY

On average, a citizen of the Netherlands travels an average of more than 10 thousand passenger kilometres per year within the Netherlands [CBS, 2017]. More than 78 percent of the total kilometres driven by Dutch passenger cars is accounted for by private cars. A private car owner drives on average nearly 12 thousand kilometres per year [CBS, 2019b]. As can be seen from table 2.1, the highest proportion of the kilometres travelled is work-related. This work related distance is mainly covered by the car, see table 2.2. 68.5% of the total work related distance travelled is made by car. The distance travelled to and from work on a working day depends on whether someone works part-time or full-time [CBS, 2019a]. Men who work more than 30 hours a week drive an average of 23 kilometres a day to and from work, for women this is almost 18 kilometres. For people who work 12 to 30 hours, the daily distance travelled is lower. Men travel more than 12 kilometres, and women almost 10 kilometres [CBS, 2019a].

Table 2.1: Mobility of Dutch citizens by travel motive. Adapted from: [CBS, 2017]

	To/from work (%)	Visit/Stay (%)	Sport/hobby /horeca (%)	Shopping /groceries (%)	Education/course and kindergarten (%)	Touring /walking (%)	Other (%)
Distance travelled	29.9	18.6	19.1	9.2	6.9	3.4	12.8

Table 2.2: Distance travelled per travel mode for commuting trips per year in the Netherlands. Adapted from: [CBS, 2017]

Mode of transport	Car (driver) (%)	Train (%)	Bicycle (%)	Car (passenger) (%)	Bus/tram/metro (%)	Foot (%)	Other (%)
Share	68.5	11.8	6.5	5.5	2.8	0.8	4.1

2.2.3. FOCUS AREAS

Areas can be indicated in different ways. This research uses the classification used in the report of Serwicka and Swinney [2016]. The first distinction is made between city areas and non-city areas. City areas consist of city centres and suburbs. The non-city areas consist of the hinterlands and the rural areas. To date, there is no research available on how residents of city and non-city areas in the Netherlands would react to shared mobility services in mobility hubs. In the Netherlands, problems of high car ownership occur in all areas, both city and non-city areas [CROW, 2008]. Moreover, the high car ownership puts a lot of pressure on the public space, leaving little room for a pleasant living environment [CROW, 2008]. Moreover, the Dutch municipalities and Sweco are interested in the effects on car use and car ownership in these areas. Therefore, this research focuses on all four areas.

2.2.4. IMPACT IN THE LIVING ENVIRONMENT

The car takes up a lot of space compared to other modes, as shown in figure 2.1. Both a moving and parked car has a large impact on space. Due to the space that parked cars take up in public areas, i.e. not on private ground, there is less space for other facilities such as a park, wide pavement or a park. Therefore, to a large extent, the car causes a deterioration of the living environment in cities [Natuur & Mileu, 2020].

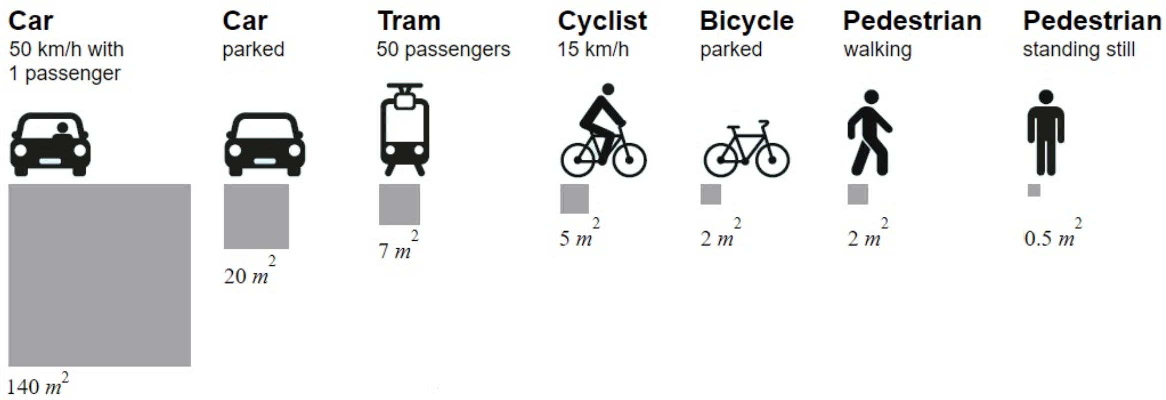


Figure 2.1: Use of space by mode of transport. Adapted from: [Natuur & Mileu, 2020]

2.3. SHARED MOBILITY

This research focuses on electrically powered shared mobility services in mobility hubs. To underpin this focus, background information is required on different shared mobility systems and mobility hubs. Section 2.3.1 discusses why the focus in this research is on fully electric shared mobility services, presents the different modes and systems and their application. Section 2.3.2 discusses mobility hubs and their requirements. Section 2.3.3 discusses shared mobility users.

2.3.1. E-MOBILITY SYSTEMS

In this research the focus is exclusively on electrically powered shared mobility services. Currently there are already many shared mobility services that are electrically powered, examples of which can be found in figure 2.2. Moreover, facilitating shared mobility services is one of the approaches to make a city or village more liveable and sustainable [Gemeente Amsterdam, 2019]. Since vehicles with fossil fuels have higher emissions than electrically powered cars offering electric shared mobility vehicles would contribute to a transition to a more liveable city [Natuur & Mileu, 2020]. Furthermore, facilitating mobility hubs for villages and cities are plans for the coming years. Since a transition to electrically powered vehicles is in progress, it is realistic to focus only on electrically powered vehicles from a future perspective [McKinsey & Company, 2020].

In the next section only the shared modes that will actually be offered in the mobility hub according to the definition in this research will be discussed. The shared modes are selected on the basis of three criteria. The first criteria is that the mode must be electrically powered. Secondly, the mode must be present in the Dutch transport system. This means that they are legally allowed on the road and that they are available in the Netherlands. The selected transport modes will be used as alternatives in the stated choice experiments.

Two changes can occur when shared mobility is offered. First of all there might be a substitution or a reduc-

Figure 2.2: Examples of shared mobility providers in the Netherlands. The car on the left is an electrically powered Smart by car2go. The moped in the middle is an electrically powered moped by felyx. The bicycle on the right is an electrically powered bicycle by Urbee.

tion of trips of one conventional mode in favor of a new mode offered. And next to that, it may happen that more trips are created or extended trips take place that never took place before. For example, longer trips can be made with an electric bike for the same effort as a normal bike [Becker and Rudolf, 2018]. The same attributes that influence the user profile affects user behaviour. As a result, different outcomes will be found for different countries in terms of usage behavior. However, the literature can give an indication of how people make use of shared mobility. For the different shared mobility systems, table 2.3 shows the trip length and the usage peak moments. The average trip length of an electric car is 28 kilometers while for micro-mobility the trip lengths are mainly not longer than 5 kilometers, and usually around 2 kilometers. Table 2.3, shows that e-bikes are used during commuting peak hours. This can be explained by the fact that e-bikes are commonly used for commuting [Liao and Correia, 2019]. The use of EVs is more spread over a longer period of time. Lastly, e-moped is mainly used early in the evening.

Table 2.3: Trip length and peak usage of shared mobility service trips. Adapted from: [Liao and Correia, 2019]

Mode	Trip length	Peak usage
E-car	Mean length 28 km [Kramer et al., 2014] Free-floating: 27 min (actual driving time 15 min) [Sprei et al., 2019]	Weekday: 3-8 PM Weekend: 2-8 PM Weekend higher than weekday [Hu et al., 2018]
E-moped	4-5 km 15-20 min [Howe, 2018]	Weekday: early evening Weekend: continuous increase in the afternoon and evening
E-bike	Most frequent trip 2 km [Romanillos et al., 2018] 1-3.5 km [Guidon et al., 2019]	Weekday: morning commute, afternoon and evening [Romanillos et al., 2018]

Electric cars are the most commonly chosen and researched mode within shared e-mobility [Liao and Correia, 2020]. It is expected that shared e-cars will accelerate the transition from conventional combustion engine cars to the use of EVs [BCG, 2018]. Trips made with electric shared cars are mainly shorter than trips made with conventional vehicles [Liao and Correia, 2020, Sprei et al., 2019]. The user of the shared e-car will not have to deal with high purchase costs [Liao and Correia, 2019]. Positive effects of shared cars can be seen for Bremen in Germany [Schreier et al., 2018]. In this city, two providers offer shared cars. A study conducted in 2017 shows that shared car users own fewer private cars, that the users make less trips with a car and instead opt for more environmentally friendly modes [Schreier et al., 2018]. The same results and effects can be found for some car users in the Netherlands [Ettema, 2018]. Another result from the study conducted in Bremen shows that for each shared car offered replaces 16 private cars, and on top of that it prevents the purchase of new private cars [Schreier et al., 2018]. Another positive side-effect is that the reduction in car ownership has led to a decrease in demand for parking spaces. A study by PBL (2015) on car sharing in the Netherlands shows that almost a third of car sharers either sell their own car or do not buy an extra car. Prior to the introduction of car sharing, car sharers typically owned 1 car per household, which has decreased to 0.7 car per household since car sharing was launched. However, car sharing often replaces a second or third car. Car sharers in the Netherlands drive 15 to 20 percent less car kilometres than before they shared a car [Nijland et al., 2015].

Micro-mobility includes vehicles with a maximum weight of 500 kg and designed for small distances. They are typically used for a distance of up to 5 kilometres [Liao and Correia, 2019]. In this literature review only the vehicles that are legally allowed on the road in the Netherlands will be discussed. Other forms of micro-mobility that are popular in other countries, such as the e-scooter, will therefore not be covered. The Ministry of Infrastructure and Water Management is currently considering allowing e-scooters on the public roads. However, it will take a long time before the new rules are in place. The distances in table 2.3 are typical distances where shared mobility can be a good alternative for the private car [Smith and Schwietermann, 2018, Suchanek, 2018]. When these distances are longer for shared e-bikes, the costs will be higher and it will require more physical effort [Liao and Correia, 2019]. The largest group of users of the shared e-moped are young people [Howe, 2018]. The shared moped is mainly used for commuting or leisure time activities. In addition, users of shared mopeds are also users of shared cars and shared bikes. The e-moped market is an emerging market that has not been around for very long [Howe, 2018].

A study by de Kruijf et al. [2018] conducted in the province of North Brabant shows that the advent of the shared e-bike has positive effects on a reduction in car use. The e-bike is currently used for two-thirds of commute trips, which has resulted in a reduction of car use by about half. An important factor for using the e-bike is that a longer acceptable distance can be covered compared to the conventional bicycle [de Kruijf et al., 2018].

2.3.2. MOBILITY HUBS

The composition of components of a mobility hub depends on its location and its purpose. Each mobility hub has different target users with different characteristics. Therefore there are no off-the-shelf mobility hubs that can be applied to all locations and mobility hubs are unique to each location [Advier, 2019]. In general, mobility hubs consist of four components [Advier, 2019]. These four parts can be recognised in figure 2.3. Shared mobility must be offered, such as shared cars, shared mopeds and shared bikes. Facilities related to mobility must be present, such as bike parking and electric vehicle charging piles. There must be public transport, such as a bus station or a train station. Finally, facilities related to non-mobility services, such as delivery lockers and snack kiosks, should also be present.

Figure 2.3: Example of a mobility hub. Retrieved from: [Advier, 2019]

There are many different classifications of mobility hubs depending on the location and country. Consequently, there are many definitions for mobility hubs. Due to the wide variety of definitions of mobility hubs an appropriate definition of a mobility hub is required for this research. The definition of a mobility hub is the result of a combination of other definitions of mobility hubs [Advier, 2019, Hely, 2020, Share North, 2017].

A mobility hub is a multi-modal mobility hub where a combination of different shared mobility services are offered. These services include shared e-cars, e-mopeds and e-bikes. Facilities that can be offered at a mobility hub are not included in this study. This makes a mobility hub simply a parking facility where parking spaces are only available for shared mobility modes.

2.3.3. SHARED MOBILITY USERS

The advent of shared mobility is not accepted and used equally by every population group. This is due to the fact that people do not like to change their habits. In the Netherlands, shared mobility is mainly used by young people living alone or by families with small children. These groups are commonly known as the early adopters. It concerns higher educated people, who do not own a car and who live in cities [KiM, 2015]. The users of the shared mobility had prior to the arrival of the shared mobility modes limited access to a car, usually public transport users and were fanatical bicycle users [Liao and Correia, 2019]. The second group where shared mobility is accepted are families with young children, who are dependent on two cars. This group can save costs by giving up the second car and opting for shared mobility [Münzel et al., 2019]. A literature study by Liao and Correia [2019] shows that the different mobility systems are preferred by different target groups. This means that there is a difference in age, education and income level per type of shared mobility. This could be explained by the different attributes of the modes. However, the literature study for the acceptance of the different shared mobility services originates from different countries. Therefore, it provides no direct insight into the shared mobility users and acceptance of the various shared mobility services in the Netherlands.

2.4. MODE CHOICE

Literature study is used to obtain a set of factors that can influence mode choice. These factors will be studied in discrete choice modelling to determine the effect of mobility hubs on the use of shared mobility and car ownership of Dutch citizens.

2.4.1. MODE CHOICE DEFINITION

The decision-making process for choosing between various modes of transportation is defined as mode choice [De Witte et al., 2013]. There are many ways in which the factors can be classified, in this research the classification of De Witte et al. is used. Mode choice depends on a combination of personal socio-demographic characteristics, spatial characteristics and trip characteristic, as well as being affected by socio-psychological characteristics [De Witte et al., 2013]. The socio-demographic characteristics and the socio-psychological characteristics belong together to the traveler characteristics. The framework used in this research for the mode choice is shown in figure 2.4. The characteristics consist of a set of determinants, which are further elaborated in paragraph 2.4.2.

There are different ways people make choices. Literature distinguishes three major approaches for mode choice [De Witte et al., 2013]. The rationalist approach is the mainstream approach assuming that travelers make their choice focused on maximizing utility through minimizing travel time and costs [Shen et al., 2009]. This approach assumes that travelers make a rational choice for different alternatives and chooses the choice with the greatest utility. A spatial component is added into the decision-making process of mode choices in the socio-geographical approach. The activity schedule of the individual is also assumed as the starting point for making the mode choice [De Witte et al., 2013]. Finally, the socio-psychological approach aims to explain the mode choice by the attitudes of the individuals regarding the available transport means. In this approach, intentions and habits are important components [De Witte et al., 2013].

2.4.2. MODE CHOICE DETERMINANTS

The framework in figure 2.4, that distinguishes different types of characteristics, is used to structure the mode choice determinants [De Witte et al., 2013]. Socio-demographic characteristics and socio-psychological characteristics are considered as traveler characteristics [De Witte et al., 2013]. The determinants of traveler characteristics are individual characteristics that are different for each traveler [De Witte et al., 2013]. The second group is the spatial characteristics, that consists of determinants for the spatial determinants and individual characteristics that provide information about the traveler [De Witte et al., 2013]. The last group is the trip characteristics, which consists of determinants for the trip characteristics and individual characteristics that provide information about the trip and the transport modes [De Witte et al., 2013]. The list of determinants was drawn up for this research, as a result only relevant determinants are considered.

TRAVELER CHARACTERISTICS

Traveler characteristics are composed of both socio-demographic characteristics and socio-psychological characteristics. First, the socio-demographic determinants are presented, followed by the socio-psychological determinants.

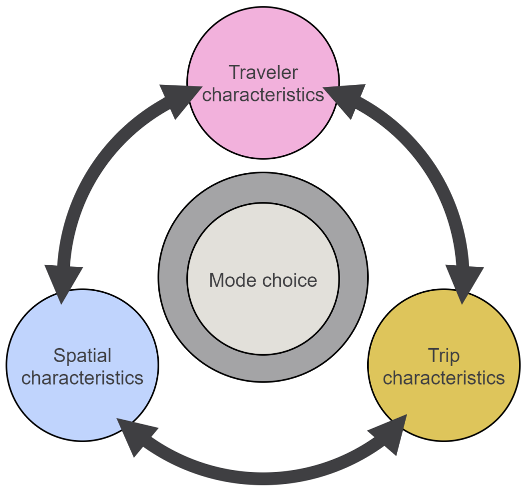


Figure 2.4: Framework for structuring mode choice determinants. Adapted from: [De Witte et al., 2013]

An individual's social status increases with age, whereas the physical ability to travel decreases with **age** [De Witte et al., 2013]. In the Netherlands, shared mobility is mainly used by young people. This group is called the early adopters [KiM, 2015]. The **gender** is an important determinant of the use of the private car. From the literature, some studies show that more women use private cars, while other studies show the same for men [De Witte et al., 2013]. It is more likely that the interdependencies between gender and other determinants, such as household type or occupation, are more decisive for mode choice than gender alone [De Witte et al., 2013]. The **education level** determines the type of work, income and lifestyle of individuals. Higher educated people tend to earn more, which makes them more inclined to use the private car for commuting trips De Witte et al. [2013], Pickery [2005]. For education level as well, the interdependencies with other determinants are more decisive for mode choice than level of education alone [De Witte et al., 2013]. The **occupation** of a person is related to income and car ownership [O'Fallon et al., 2004]. Apart from the type of work, the employer often has an influence on the mode of choice of its employees, and in particular for commuting trips [Bastin, 2011]. Part-time workers are more likely to take the car [O'Fallon et al., 2004], and self-employed are more likely to use public transport for commuting [Limtanakool et al., 2006]. For occupation as well, the interdependencies with other determinants are more decisive for mode choice than occupation alone. **Income** is among the key determinants in mode choice [De Witte et al., 2013]. Income has a positive relationship with car use, and an inverse relationship with the use of public transport [De Witte et al., 2013, Vasconcellos, 2005]. People on lower incomes, on the other hand, have travel restrictions due to less access to cars [Vasconcellos, 2005]. The **household structure** has consequences on how many cars are owned in a household [De Witte et al., 2013]. Research by [Cirillo and Axhausen, 2001, De Palma and Rochat, 2000] shows that when the size of the household increases, more private cars are used. In particular, children in a household tend to increase car use [Cirillo and Axhausen, 2001, Limtanakool et al., 2006]. **Car ownership** is an important determinant that influences mode choice [De Witte et al., 2013]. Car use for a trip increases as more cars are owned in a household [Cirillo and Axhausen, 2001, Limtanakool et al., 2006]. If a household has a company car, the car is often chosen for commuting trips [O'Fallon et al., 2004].

A positive **experience** in the past with a mode can have positive effects on mode choice at this moment, and vice versa [De Witte et al., 2013]. The experience of a traveler on a road network can also influence the mode choice. The private car is chosen more often, if a traveler has used the car for commuter journeys more often [De Palma and Rochat, 2000]. **Familiarity** for a certain mode stems from traveler's experiences. Familiarity is related to the knowledge that travelers have for certain modes that are available, and this can facilitate mode choice [De Witte et al., 2013]. An individual's **lifestyle** can have consequences for the mode choice. The lifestyle choices a traveler makes include decisions about education and occupation. These two decisions affect income and car ownership [De Witte et al., 2013]. The **perception** that travelers have about a certain mode is important for the mode choice [De Witte et al., 2013]. Perceptions that people find important for a mode include comfort, appearance and perceived safety. Preference comes from attitudes and perceptions of travelers [van Acker et al., 2010]. Travelers perceive travel time and travel costs differently for different modes

[De Witte et al., 2013]. A positive **attitude** towards trying out new technologies can ensure that electrically shared services will be used earlier. In addition, a positive attitude towards sharing could lead people to adopt to the use of shared mobility.

SPATIAL CHARACTERISTICS

The **housing** decision means that the traveler has to a certain extent the freedom to choose where to live. This decision influences trip characteristics determinants such as travel distance, which in turn affects travel time and travel cost [De Witte et al., 2013]. This means that the housing decision can affect the mode choice. **Urban density** is defined as the ratio of inhabitants and built-up area [De Witte et al., 2013, Hollevoet et al., 2011]. The urban density can influence the travel behaviour of residents. The urban location of a household positively affects the use of public transport [Cirillo and Axhausen, 2001]. The presence of a **parking** space has great influence on mode choice, and in particular in densely populated areas [Kajita et al., 2004]. Reducing parking spaces in a neighbourhood can reduce the use of cars of inhabitants and increase the use of public transport [De Witte et al., 2013]. As the distance from a house to a car increases, car use may decrease.

TRIP CHARACTERISTICS

The **access distance** is the distance from home to a mode. The maximum access distance varies for different modes. Research has shown that walking distance is an important factor in the use of shared cars [Dieten, 2015]. In the Netherlands a maximum of 5 minutes walking time is considered reasonable in order to use a shared car. As this walking time increases, the willingness to use a shared car decreases. Similarly, **egress distance** is an important factor for the use of shared mobility. It is the distance from a parking space to the activity. As this distance increases, the willingness to use a shared mobility alternative decreases. **Travel distance** is an important determinant for mode choice. Travelers prefer to take faster travel modes for longer distances [De Witte et al., 2013]. **Travel time** is related to the distance to be covered. Travel time is an important determinant of mode choice, and is assessed differently for different travel motives [De Witte et al., 2013]. **Travel cost** is an important factor in the mode choice [Kajita et al., 2004]. People are price sensitive, but the degree of their sensitivity varies depending on factors such as the purpose of the trip. [Annema, 2002]. **Travel motive** is related to travel need, which lies at the basis of the mobility demand and is consequently a key determinant in the mode choice [De Witte et al., 2013]. For a business traveler, having a private car is important [Limtanakool et al., 2006, O'Fallon et al., 2004]. The **departure time** affects the mode choice because in some cases a different mode can shorten the travel time. Finally, the **weather conditions** might influence the mode choice. The use of active modes, such as walking or cycling, are less likely in bad weather than in good weather.

2.5. KNOWLEDGE GAP AND CONCEPTUAL FRAMEWORK

This chapter shows that the adoption rate for the use of shared mobility services is very low. Moreover, shared mobility services will mainly be used to replace the second or least used car. To date, there is no literature available on the adoption rate of the use of different shared mobility services if these are offered together at one location, such as in a mobility hub. The effect of mobility hubs in city and non-city areas on car use and car ownership is not known and should therefore be researched.

Since there are no data available from pilot locations of mobility hubs, it is necessary to conduct stated choice experiments to gain insights into the effects of mobility hubs on car use and ownership. The factors that can influence mode choice are used to construct a conceptual framework, see chapter 4. The stated choice experiments are designed using that framework. The impact of factors that might influence mode choice can be examined with this approach. Through the experiments, it is possible to gain insight into people's mode choice behaviour. Ultimately, it is possible to obtain a comprehensive insight into how the various factors are related to the mode choice, both in the short and long term. A disadvantage of this is that it concerns experiments, so in reality people may react differently.

3

METHODOLOGY

This chapter deals with the methods used in this research. Section 3.1, deals with the conceptual framework that is the foundation for the design survey and the stated choice experiments. Section 3.2, discusses stated preference data and experiments. Next in section 3.3, discusses the modelling techniques used to analyse the stated choice data. Finally, section 3.4 elaborates on the recruitment procedure and sample.

3.1. CONCEPTUAL FRAMEWORK

Based on the literature, factors are identified that might influence the mode choice, see section 2.4. The factors are discussed and debated with experts in the field of mobility, see appendix A. The result is a conceptual framework, see section 4.3. The conceptual framework consists of a trip with the private car and a trip with shared mobility alternative with the various factors that may influence the mode choice. The conceptual framework is used for the design of the short-term and long-term mode choice experiment. How the short-term and long-term are related is explained in section 4.1. The factors that recur as attributes in the stated choice experiments should have realistic values. This ensures that the choice situations are understandable for the respondents of the survey. The attribute levels are therefore based on situations in the Netherlands, see section 4.4.

3.2. STATED PREFERENCE METHOD

The aim of this research is to determine people's willingness to use shared mobility in mobility hubs. Since mobility hubs do not yet exist, stated preference experiments were chosen as research method in order to collect choice data. Respondents are requested to choose between various alternatives in hypothetical choice situation in these stated choice experiments. The main advantage of stated preference experiments is that it is possible to include non-existent alternatives, attributes and attribute levels. However, stated preference data can contain hypothetical bias. It is uncertain whether people will choose the same alternative in practice. Since the implications of the decisions are not perceived, this bias occurs. Moreover, the respondent has complete information about the choice situation whereas in practice this is usually not the case [Molin, 2018]. This preference data is essential to study the decision-making process of travelers. The stated preference method has the advantage that the hypothetical choice situations can be fully constructed to suit the research objectives [Hensher et al., 2015].

3.3. DISCRETE CHOICE MODELLING

Discrete choice modelling is a quantitative method for analyzing stated preference data. It assumes that the choice made is a rational choice between the different alternatives in the hypothetical choice situations. Using discrete choice modelling the choices of respondents between different alternatives can be described, explained and predicted [Araghi et al., 2014].

3.3.1. DECISION RULE

discrete choice modelling is based on four assumptions [Ben-Akiva and Bierlaire, 1999]. To start with, a decision maker has to make his choices or make a decision in the experiments. Secondly, the decision-maker has to make a choice from a choice set with various alternatives. Thirdly, the various alternatives from the choice set must contain attributes that define the alternatives. The decision-maker takes these attributes into account in the choice process. The final assumption is the decision rule. The decision rule is the philosophy used by the decision maker in order to make a choice [Ben-Akiva and Bierlaire, 1999].

One of the most commonly used decision rules is the random utility maximization. The philosophy behind this was developed by McFadden. RUM assumes that each decision-maker makes a choice for the alternative for which they experience the highest utility [McFadden, 1973]. The model estimates in this research are made based on the RUM decision rule. The random utility maximization decision rule can be defined in formula form as follows.

$$U_i = V_i + \varepsilon_i = \sum_m \beta_m \cdot x_{im} + \varepsilon_i \tag{3.1}$$

Where,
U_i is the total utility for the alternative i
V_i is the observed utility for the alternative i
ε_i is the random error component for the alternative i
β_m is the parameter estimate for attribute m
x_{im} is the attribute value of attribute m for alternative i

3.3.2. MODEL SPECIFICATIONS

There are various models that can be used to predict the attribute weight and the choice probability. In this research, the multinomial logit model and the extended MNL model are used. The extended MNL model is based on the MNL model to which variables are added.

The MNL model is the most widely used discrete choice model [Adler and Ben-Akiva, 1979, Train, 2009]. This model assumes that the error term is independently and identically distributed. The probability of an alternative is indicated by the formula 3.2. The model formula is a closed form equation, which ensures short computation times.

$$P_n(i) = \frac{e^{V_{in}}}{\sum_{j \in C_n} e^{V_{jn}}} \tag{3.2}$$

Where,
$P_n(i)$ is the probability for individual n that an alternative i is chosen
V_{in} is the utility of alternative i of individual n
C_n is the choice set of j alternatives of individual n

3.3.3. MODEL PERFORMANCE

To evaluate the performance of the estimated models. This research uses the likelihood ratio test statistic and the McFadden's rho-squared as measures

LIKELIHOOD RATIO TEST STATISTICS

Since this research uses an MNL model and an extended MNL model, it is important to determine whether the model with more parameters is a significantly better model. This is assessed using the likelihood ratio statistic, which can be calculated using formula 3.3.

$$LRS = -2 \cdot (LL_A - LL_B) \tag{3.3}$$

Where,
LL_A iis the final log-likelihood of the model with the least parameters
LL_B is the final log-likelihood of the model with the additional parameters

MCFADDEN'S RHO-SQUARED

McFadden's rho-squared relates the performance of the predicted model to the model's null-version [Chorus, 2018]. In the null-version of the model, all attribute weights are set to zero. The performance of the model can be calculated using equation 3.4.

$$\rho^2 = 1 - \frac{LL(\beta)}{LL(0)} \tag{3.4}$$

Where,
$LL(\beta)$ is the final log-likelihood
$LL(0)$ is the null log-likelihood

The ρ^2 indicates the quality of the model. A perfect fit is found when $\rho^2 = 1$. Whereas, $\rho^2 = 0$ indicates that the model is not good and that it similar to 'throwing a dice' [Chorus, 2018]. Table 3.1 indicates the interpretation of the rho-squared values.

Table 3.1: Interpretation of McFadden's Rho-Squared. Adapted from: [de Looff, 2017, Tjon Joe Gin, 2019]

Rho-squared value	Model fit
ρ^2 <0.1	Limited
0.1 <ρ^2 <0.3	Reasonable
0.3 <ρ^2 <0.5	Reasonable well
ρ^2 >0.5	Good

3.4. RECRUITMENT PROCEDURE AND SAMPLE

Participants of the research should meet two requirements. First, participants must be over 18 years of age. In the Netherlands, 18 is the age at which, if in possession of a driver's license, it is allowed to drive. Secondly, participants must be in possession of a private car.

3.4.1. SAMPLE SIZE

Equation 3.5 can be used as a guideline to determine the minimum number of respondents needed in the experiments for the discrete choice modelling [Johnson and Orme, 2003, Orme, 1998]. Since this is a guideline, it is not a strict requirement.

$$N = 500 \cdot \frac{C}{Q \cdot A} \tag{3.5}$$

Where,
N is the minimum number of respondents required
C is the greatest number of attribute levels for one of the attributes
Q is the number of choice tasks in the experiment
A is the number of alternatives in the choice tasks

3.4.2. RECRUITMENT OF RESPONDENTS

For this research, the idea was to recruit respondents who live in the Randstad. The large number of respondents required different strategies of approaching respondents for the survey, see section 6.1.1. Through the different strategies an attempt was made to get a good sample from Dutch society. It is important to obtain a sample that represents the population well in order to be able to estimate the population's behaviour. Moreover, because of the different strategies, the data set could be obtained faster. The strategies for the survey were:

- On LinkedIn and Facebook a post was shared with a short description about the research, including a link to the survey. In addition, the survey was shared on Facebook with groups regarding (safe) mobility topics.

- A flyer with a QR code was given to people on the street. The flyers were handed out in the centre of Amsterdam on three different days (October 29 and 30, and November 6). The flyer's design is shown in figure C.2. By handing out flyers, people can complete the survey in their own time. Besides, this way many different people can be approached to fill out the survey.
- The survey was published on the SurveyCircle website. SurveyCircle is a platform where researchers can participate in each other's surveys, providing fast and reliable data free of charge. In SurveyCircle the survey was shared in the Dutch research group. Therefore, only Dutch respondents were obtained.
- Finally, the survey was shared among direct friends and family, and asked if they could participate in the survey. On top of that, they were asked if they could share the survey with other groups of friends and family.

3.4.3. ETHICAL CONSIDERATIONS

This research must take ethical considerations into account, since respondents are taking part in the survey. In this research, the GDPR requirements [Groot Kormelink, 2018, HREC, 2018] have to be respected. The anonymity of the respondents is guaranteed as the survey is anonymous both via the link and the qr-code. The respondents do not have to provide any personal data. However, respondents are asked for their postal code, but this is voluntary and therefore optional. The anonymity of the survey is made clear at the start of the survey. The goal of the survey is also explained. It was also made clear that the data is anonymous and cannot be traced back to a person. However, at the end of the survey, the respondent has the opportunity to leave his/her e-mail address in order to send the final research to these persons by e-mail. Respondents are able to leave the survey at any time.

Qualtrics is used to program the survey. Qualtrics is chosen because it meets the GDPR requirements. This software package is available with a TUD licence. Moreover, Qualtrics uses the TU Delft network disk to store the survey data [Groot Kormelink, 2018].

4

CONCEPTUAL FRAMEWORK

This section deals with the conceptual framework which is the basis for the design of the stated choice experiments. Section 4.1, discusses the focus effects of this research and how they are related. Section 4.2, discusses the travel concept. It explains how trips take place with the private car and with shared mobility alternatives. Then section 4.3, discusses the conceptual framework. Finally, section 4.4 discusses the overview of the attributes with the attribute levels.

4.1. SHORT AND LONG TERM EFFECTS

The scope of this research covers the effects of mobility hubs on car use and car ownership. These two effects are labelled in this research as short-term and long-term effects respectively. The short-term and long-term effects are related to each other to a certain extent. The short-term effects provide insight into the willingness to use shared mobility services for commuting trips. It provides insights in the impact of the factors on the mode choice for commuting trips and the preference of the shared mobility alternatives for the commuting trips. Commuting trips are part of the total trips. Insight in the willingness to use shared mobility services for commuting trips gives a more profound insight in the general willingness of people to use shared mobility services. The long-term effects provide insight into the willingness to use shared mobility services for all trips and therefore all travel motives, and moreover, insight into the willingness to give up the private car. It provides insight into the impact of the factors on the giving up of the private car and the preference of shared mobility alternatives for all trips. The short-term effects focus on commuting trips, and the long-term effects on all trips. The ways in which trips with the private car and shared mobility services take place are described in the travel concept in section 4.2. For both short- and long-term effects, the travel concept shows how trips can take place. The conceptual framework is based on the travel concept. The conceptual framework is the result of the travel concept, the factors that can influence the mode choice from the literature study and expert interviews, see section 4.3. The conceptual framework is the basis for the design of both the short-term and long-term mode choice experiments. However, only parts of the conceptual framework are used for both experiments. The parts used for the experiments are further explained in sections 4.3.1 and 4.3.2. The two experiments provide insights into the impact of factors that can affect mode choice in both the short and long term.

4.2. TRAVEL CONCEPT

A car trip takes place as shown in the top flow 1 in figure 4.1. The trip consists of three parts: access trip from home to car, the actual car trip, and the egress trip from the car to the destination. In the same figure 4.1, bottom flow 2, it can be seen that a trip using a shared mobility service is reasonably the same. The shared mobility service trip is the bottom flow 2. Again, the trip consists of three parts: an access trip from home to mobility hub, a shared service trip between the two mobility hubs, and an egress trip from the mobility hub to the destination.

For the car trip, top flow 1 in figure 4.1, the access time is the total time for the driver from leaving home until the moment of driving away with the car. The car trip time represents the total travel time from the moment

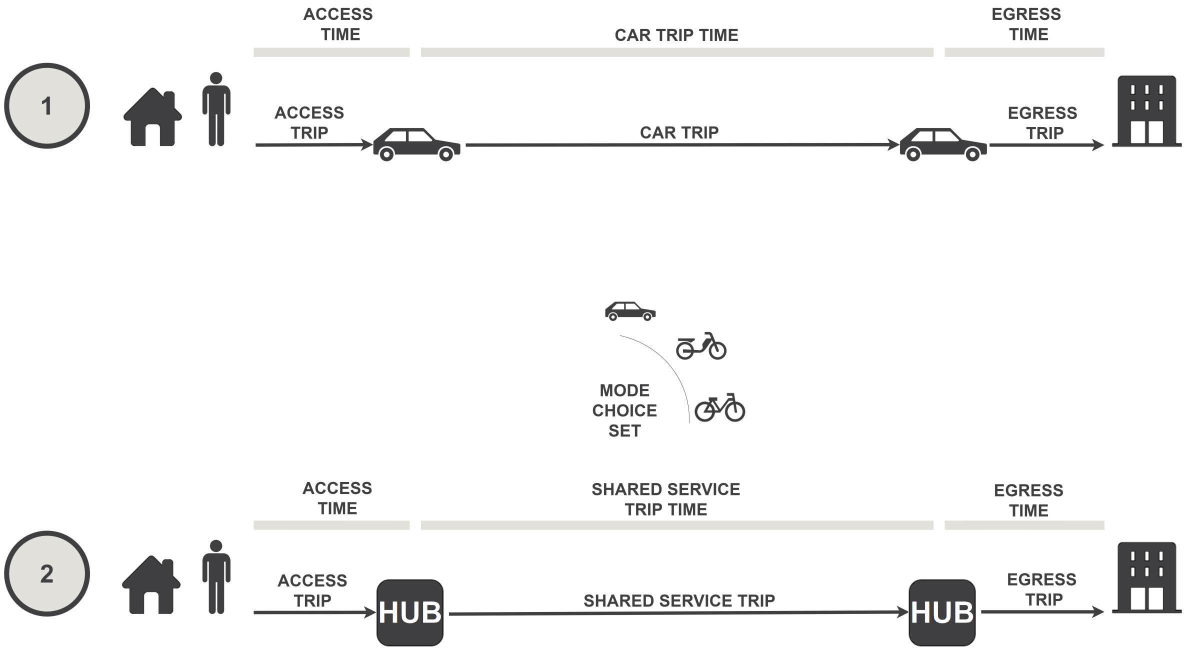


Figure 4.1: Travel concepts, overview of a car trip and a shared service trip.

the car is driven away to the place of destination where the car is turned off. The egress time, is the total time that it takes for the driver to leave the car up to the moment when the final destination is reached.

For the trip using a shared mobility service, bottom flow 2, resembles top flow 1. The access time here is the total time it takes for the driver to get from home to the mobility hub, to unlock the mode, to enter the mode, and up to the moment of driving away. The shared service trip time is the total time it takes for a certain mode to travel between two mobility hubs. The modes must always be returned to a mobility hub at the end of the trip, since the offered modes are station-based and not free-floating. The shared service trip time depends on the selected mode in the first mobility hub. As mentioned before, a shared e-car, e-moped and an e-bike are offered in mobility hubs. The egress time is the total time for a driver to exit the mode, lock the mode, and to arrive at the final destination.

Mobility hubs allow people to make a shared service trip. Apart from opting to use their own car, people now also have the choice to use a shared e-car, e-moped or e-bike for a trip. In the short term, the advent of mobility hubs may have consequences for private car use. While in the longer term it may affect car ownership. If the services offered in mobility hubs is attractive enough, car owners can decide to give up their least used private car and use the shared mobility services offered in the mobility hubs for all trips.

4.3. CONCEPTUAL FRAMEWORK

Since the total time of a survey should not exceed more or less 15 minutes, it is important to select only the most important factors for the conceptual framework. The factors that can influence the mode choice are discussed with experts in the field of mobility and transport, as indicated in appendix A. The result is the conceptual framework shown in figure 4.2. The spatial characteristics belong to the location of the car owner's house. The car owner has different characteristics, which are covered by the traveler characteristics. The trip characteristics consist of three different sections. The general trip characteristics, the car trip characteristics and the shared service trip characteristics. General trip characteristics are context variables of a trip. The car trip characteristics are obviously the characteristics that belong to a car trip. The same logic applies to the shared service trip characteristics, which are the characteristics that belong to the shared service trip. This section only discusses the factors that are not included in the conceptual framework. Furthermore, the usage scenario is added despite that it was not directly found in the literature, but turned out to be relevant after the interviews with experts. The usage scenario and the idea behind it is elaborated in more detail in this section as well.

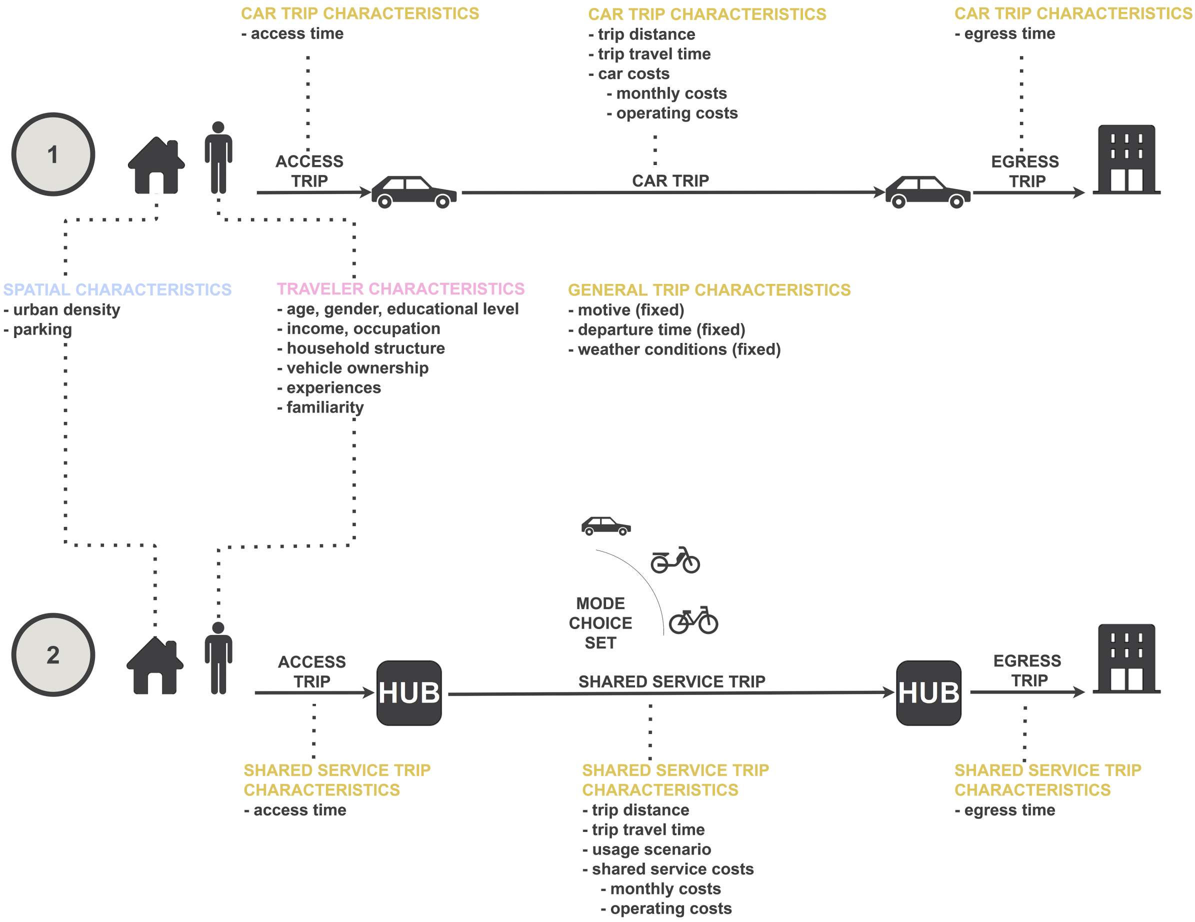


Figure 4.2: Conceptual framework.

Since people have a better perception of time than of distance, access distance and egress distance are changed to access time and egress time. This allows the respondents to make a more meaningful trade-off in the experiments due to a better sense of time than of distance. The housing decision gives the traveler to a certain extent the freedom to choose where to live. As can be read in the previous chapter, this affects the mode choice. Respondents have to indicate in the survey the type of residential area they live in. Respondents will have to make choices based on their current living environment. In the experiments, they will not have to make choices for situations in which respondents have to imagine that they are living in a different living environment. For this reason, it is decided that housing is not included in the conceptual framework for this study. Lifestyle of a person depends on and is based on different characteristics, as described in the previous chapter. Since it depends on different characteristics, lifestyle is not directly measurable. Therefore, it will not be included in the conceptual framework. Perceptions are, among other things, a combination of experiences and attitudes. Due to the fact that perceptions are composed of different characteristics, perceptions are difficult to measure. In order to determine the respondents' perceptions of comfort, appearance and perceived safety, many statements in the survey are required. Assessing the statements takes a lot of time. Consequently, perceptions are not included in the conceptual framework. Attitudes towards trying out new technologies can provide insight into the potential willingness to use shared mobility services. To determine the attitudes of respondents, again statements in the survey are required. Due to time limitations of the survey, attitudes are not included in the conceptual framework.

The preference for the use of the different shared mobility alternatives of car users is not known. Therefore, a usage scenario attribute is added to the shared service trip characteristics. The usage scenario attribute allows insight into how and how often car users want to use the various shared mobility services as a substitute for the private car. The usage scenario attribute is further explained in section 4.4.

4.3.1. CONCEPTUAL FRAMEWORK FOR SHORT-TERM MODE CHOICE EXPERIMENT

The short-term choice experiment is about the mode choice for commuting trips. Hence, the motive is fixed. The departure time for the choice situations in the short-term mode choice experiments are also fixed. The reason for this is that the departure time for commuting trips from home to work usually takes place in the morning rush hour. The choice situations for the short-term mode choice experiments assume commuting trips in dry weather. In the Netherlands, it rains only 8% of the time [Lammerse, 2018]. For simplicity's sake, this research assumes that the trips take place in dry weather. Therefore the weather conditions are also fixed. The travel costs for commuting trips are only based on the operating costs for both the private car and the shared mobility alternatives. Monthly costs could be divided over travel costs if the number of monthly trips of respondents is known. A highly personalised stated choice experiment increases the complexity of the experiment. While, the interest is in the impact of operating costs on the willingness to use shared mobility services for commuting trips. Therefore, only the operating costs for both the private car and the shared mobility services are included. The travel time depends on the travel distance to work and the mode and is therefore fixed, this is further explained in chapter 5. The access time and egress time are however attributes in the short-term mode choice experiment, which is discussed in section 4.4.

4.3.2. CONCEPTUAL FRAMEWORK FOR LONG-TERM MODE CHOICE EXPERIMENT

In the long-term mode choice experiment the respondents have to make a choice whether they would give up the least used private car and start using the modes from the mobility hub for all trips. This requires, among other things, information about the car costs for the private car alternative and the shared service costs for the shared service alternative. The shared service alternative is the mobility hub alternative in the long-term mode choice experiment. For the long-term mode choice experiment, the private car costs consist of the monthly costs and the operating costs. The same applies to the mobility hub alternative, the shared service costs consist of the monthly costs and the operating costs of the three modes offered. The egress trip from the car park or mobility hub to the activity is not included in the design of the long-term mode choice experiments. There is no interest in the walking times on the activity side of the trips but only on the home side. The home side is where the problems of car ownership take place. Since it is unclear how car users intend to use the modes from the mobility hub, a usage scenario attribute is added to the shared service trip characteristics. This attribute enables to examine how the different modes from the mobility hub will be used by car users.

4.4. OVERVIEW OF SELECTED ATTRIBUTES AND LEVELS

Of all the factors identified in section 4.3, there are seven factors that recur as attributes in the stated choice experiments. These are the access time and egress time for both the private car and the shared mobility services. Operating costs for the shared mobility services. The monthly costs for the use of the mobility hub. Finally, the usage scenario for the mobility hub alternative. This section also discusses the attribute levels used in the stated choice experiments. The values associated with the different attribute levels must be realistic and understandable for the participants in the stated choice experiments [Del Giudice et al., 2019]. An overview of the attributes and associated levels can be found in table 4.2 for the private car alternative and the shared mobility alternatives.

TRIP TIME

Although the total trip time includes the access time, travel time and egress time, only the access time and egress time are attributes in the stated choice experiments. The travel time depends on the distance travelled and therefore does not vary, this is further explained in chapter 5 and appendix B.3.

The maximum acceptable distance that people in the Netherlands are willing to walk to a shared car is 330 metres [KiM, 2015]. This distance is equivalent to a 5-minute walk. For simplicity it is assumed that this maximum acceptable time also applies to the private car alternative and the shared mobility alternatives. Based on this acceptable value from literature, a lower value of 2 minutes and a higher value of 8 minutes is chosen. The access time duration of 2, 5 and 8 minutes correspond to a walking distance of 132, 330 and 528 metres respectively.

It is assumed that the acceptable walking time from home to a shared car is equal to the acceptable walking time from shared car to destination. Therefore, the values of the egress time attribute for all alternatives are equal to the values of the access time attribute for the same alternatives. Again, for the sake of simplicity, it is assumed that the maximum acceptable time also applies to the private car alternative and the shared mobility alternatives. Therefore, the egress time also consists of three attribute values of 2, 5 and 8 minutes.

TRAVEL COSTS

The travel costs consist of the operating costs and the monthly costs. The operating costs and monthly costs are fixed for the private car alternative and therefore do not vary, this is further explained in appendix B.1.

The operating costs are the price that has to be paid to travel one kilometre with an alternative. The operating costs for the shared mobility alternatives are based on the costs that have to be paid for the use of the shared mobility alternatives of Hely Hub. At the moment of this research, Hely Hub is the only operational mobility hub in the Netherlands. The operating costs per kilometre travelled for a shared e-car is € 0.175, for a shared e-moped € 0.226 and for a shared e-bike € 0.118, which is further explained in appendix B.2. Based on these values, a lower value of one third of the actual price and a higher value of five thirds of the actual price is chosen. This applies to the shared e-car, e-moped and e-bike. The values for the operating costs for the three shared mobility services can be found in table 4.2.

The monthly costs are the fixed costs associated with the use of the private car or the use of mobility hubs. The monthly costs for the use of the shared mobility alternatives are also based on the costs of the Hely Hub. As can be seen in appendix B.2, the monthly cost is € 30. Based on this value, a lower amount of € 10 and a higher amount of € 50 is chosen.

MODE PREFERENCE

The mode preference category only consists of the usage scenario attribute. The usage scenario is an alternative specific attribute for the mobility hub alternative.

It is unclear as to how car users intend to use the different modes offered in the mobility hub. Therefore, usage scenarios are added as an attribute for the long-term mode choice experiment. In the usage scenarios, the use of the different modes varies per scenario. The usage scenario is an alternative specific attribute for the mobility hub alternative. The usage scenario consists of four attribute levels. The first level is full shared e-car use, the second level is high shared e-car use, the third level is intermediate shared e-car use and the fourth level is low shared e-car use. The shared of the different modes in the mobility hub corresponding to the usage scenario levels can be found in table 4.1.

Table 4.1: Attribute level explanation for the usage scenario attribute.

Attribute level	Description
0	100% of the trips with a shared e-car
1	85% of the trips with a shared e-car, 10% with a shared e-moped, and 5% with a shared e-bike
2	70% of the trips with a shared e-car, 20% with a shared e-moped, and 10% with a shared e-bike
3	55% of the trips with a shared e-car, 30% with a shared e-moped, and 15% with a shared e-bike

Table 4.2: Attributes together with the associated attribute level values for the two stated choice experiments. Please refer to table 4.1 for the meaning of the usage scenario attribute levels.

Alternative	Category	Attribute		Level 0	Level 1	Level 2	Level 3
Private car	**Trip time**	Access time [min]		2	5	8	
		Travel time [min]			Fixed		
		Egress time [min]		2	5	8	
	Travel costs	Monthly costs [€]			Fixed		
		Operating costs [€/km]			Fixed		
Shared mobility	**Trip time**	Access time [min]		2	5	8	
		Travel time [min]			Fixed		
		Egress time [min]		2	5	8	
	Travel costs	Monthly costs [€]		10	30	50	
		Operating costs [€/km]	Shared e-car	0.058	0.175	0.292	
			Shared e-moped	0.075	0.226	0.377	
			Shared e-bike	0.039	0.118	0.197	
	Mode preference	Usage scenario		0	1	2	3

5

DESIGN OF THE SURVEY AND EXPERIMENTS

This chapter discusses the experimental design to explore short term and long term effects as proposed in the conceptual framework. First, section 5.1 discusses the specifications and designs of the experiments. Section 5.2 discusses the design of the survey.

5.1. EXPERIMENTS SPECIFICATIONS AND DESIGNS

This section discusses the choices for categories, alternatives, attributes and attribute levels for the short-term and long-term mode choice experiments. After, the design decisions of both experiments are discussed.

5.1.1. SHORT-TERM MODE CHOICE EXPERIMENT

The short-term mode choice experiments are designed to find modal shift effects for daily commuting trips. Once shared mobility is offered in Dutch cities, the possibilities for mobility alternatives are greater, allowing residents to make a different mode choice. In the following section, the essential components for the design of the short-term mode choice experiment are explained.

CATEGORIES

In this research, the possible one-way trip distance to work is divided into five groups, as shown in table 5.1. In the beginning of the survey, respondents must indicate in which group they belong. As a result, in the short-term mode choice experiment the respondents are shown choice situations that resemble their actual situation. The distance in the choice situations for which respondents are forced to make a mode choice is presented in table 5.1.

Table 5.1: Classification for the distances in the short-term mode choice experiment.

Group	**Commuting trip distance**	**Choice situation commuting trip distance**
1	0 - 15 kilometre	7.5 kilometre
2	15 - 30 kilometre	22.5 kilometre
3	30 - 60 kilometre	45 kilometre
4	60 - 90 kilometre	75 kilometre
5	90 kilometres or more	75 kilometre

ALTERNATIVES

In the short-term mode choice experiment, there are two alternative sets. This results from the willingness of people to travel a distance with a mode. It is assumed that for a distance up to 30 kilometres people are willing to travel this distance for work by private car, shared e-car, shared e-moped or shared e-bike. For a commuting trip of more than 30 kilometres, it is assumed that people are only willing to travel this distance by private car and shared e-car. The commuting trip distances with the alternative sets are shown in table 5.2

Table 5.2: Different alternatives for the short-term mode choice experiment.

	Commuting trip distance			
Mode alternatives	**7.5 km**	**22.5 km**	**45 km**	**75 km**
Private car	•	•	•	•
Shared e-car	•	•	•	•
Shared e-moped	•	•		
Shared e-bike	•	•		

ATTRIBUTES AND ATTRIBUTE LEVELS

Chapter 4 provides an overview of various factors that can influence the use of private cars or shared mobility. The factors that are included as attributes in the short-term choice experiment are access time, egress time and the operating costs as shown in table 5.3. For the distances of 7.5 and 22.5 kilometres, there are a total of eleven attributes for the four alternatives. Since there are only two alternatives for the commuting trips of 45 and 75 kilometres, there are only five attributes for these experiments.

Table 5.3: Attributes for the different alternatives in the short-term mode choice experiments.

		Alternatives			
Category	**Attributes**	**Private car**	**Shared e-car**	**Shared e-moped**	**Shared e-bike**
	Access time	•	•	•	•
Trip time	**Travel time**	Fixed	Fixed	Fixed	Fixed
	Egress time	•	•	•	•
Travel costs	**Operating costs**	Fixed	•	•	•

For the short-term mode choice experiment, all attributes have three attribute levels, as explained in section 4.4. The attributes and attribute levels used for the experiment design for the four commuting trip distances can be found in table 5.4.

The total trip time consists of access time, travel time and egress time. The different trip time components of the different alternatives are perceived differently, therefore the attributes are alternative specific attributes [Arentze and Molin, 2013]. The access time is an alternative specific attribute for all alternatives. The values for the access time attributes of the alternatives are based on realistic walking times to the private car and shared mobility alternatives in the Netherlands, see section 4.4. The travel time does not vary for the different distances, and is therefore fixed, see appendix B.3. The travel times are fixed for all alternatives in the four distance categories. The egress time is an alternative specific attribute for all alternatives. The values for the egress time attributes of the alternatives are based on the values of the access time attributes of the same alternatives, see section 4.4. The access time and egress time attributes and their attribute levels can be found in table 5.4 for the different commuting trip distances and the shared mobility alternatives.

The fare that has to be paid to use a mode for a one-way commuting trip depends on the operating costs for the alternative and the commuting trip distances. The operating costs for the private car is fixed and is based on an average car, see appendix B.1. The operating costs for the shared mobility alternatives are alternative specific attributes, see section 4.4. The fare to be paid for a commuting trip with a shared mobility alternative depends on the operating costs of that shared mobility alternative. The three attribute levels of the operating costs attribute for the shared mobility alternatives are used to obtain a low fare, a realistic fare and a high fare based on the commuting trip distance. These prices can be found in table 5.4 for the different commuting trip distances and the shared mobility alternatives.

TYPE OF EXPERIMENTAL DESIGN

The short-term mode choice experiments are labeled experiments, as the alternatives represent actual modes. For efficiency a fractional factorial design is used, resulting in a much smaller number of choice sets compared to a full factorial design. Specifically, an orthogonal fractional factorial design is used, as it allows to estimate all the main effects. Orthogonal fractional factorial design does not require prior values for the parameters. Since the short-term mode choice experiment consists of labeled alternatives with alternative specific attributes, the choice sets are created in a simultaneous way. As a result, there are no within and no between alternative correlations. The choice sets are created with the software program Ngene. Ngene is a software program that is available through TU Delft.

Table 5.4: Final attribute level values of the short-term mode choice experiment. level 1 is based on a realistic value. On this realistic value, a level 0 and level 2 value are determined. These values represent the lowest attribute value and the highest attribute value respectively. Fixed attributes are displayed as well.

		7.5 km			22.5 km			45 km			75 km		
		Level											
Alternative	**Attribute**	**0**	**1**	**2**	**0**	**1**	**2**	**0**	**1**	**2**	**0**	**1**	**2**
Private car	**Access time [min]**	2	5	8	2	5	8	2	5	8	2	5	8
	Travel time [min]		14			25			40			58	
	Egress time [min]	2	5	8	2	5	8	2	5	8	2	5	8
	Trip price		€1.87			€5.68			€11.35			€18.92	
Shared e-car	**Access time [min]**	2	5	8	2	5	8	2	5	8	2	5	8
	Travel time [min]		14			25			40			58	
	Egress time [min]	2	5	8	2	5	8	2	5	8	2	5	8
	Trip price	€0.43	€1.29	€2.16	€1.31	€3.94	€6.56	€2.62	€7.87	€13.12	€4.37	€13.12	€21.87
Shared e-moped	**Access time [min]**	2	5	8	2	5	8						
	Travel time [min]		16			53							
	Egress time [min]	2	5	8	2	5	8						
	Trip price	€0.56	€1.67	€2.79	€1.67	€5.08	€8.47						
Shared e-bike	**Access time [min]**	2	5	8	2	5	8						
	Travel time [min]		20			67							
	Egress time [min]	2	5	8	2	5	8						
	Trip price	€0.29	€0.88	€1.46	€0.89	€2.66	€4.44						

MODELS AND CHOICE SETS

For the short-term mode choice experiment, two models are used to generate choice sets with Ngene for the four categories. Two models are used since there are two alternative sets for the short-term mode choice experiment.

The first model is used to generate the choice sets for the commuting trips of 7.5 and 22.5 kilometres. The model consists of four alternatives. In total there are eleven alternative specific attributes for the four alternatives. For each of the eleven different attributes there are three levels per attribute. For the first choice set, there is an orthogonal design with 36 different choice situations. These 36 choice situations are subdivided into 6 blocks, each with 6 choice situations. The model for Ngene with the complete choice sets can be found in appendix B.4.1.

The second model is used to generate the choice sets for the commuting trips of 45 and 75 kilometres. The model consists of two alternatives. In total there are five alternative specific attributes for the two alternatives. For each of the five different attributes there are three levels per attribute. For the second choice set, there is an orthogonal design with 12 different choice situations. For these experiments, the 12 choice situations are divided into 3 blocks, each with 4 choice situations. The model for Ngene with the complete choice sets can be found in appendix B.4.1.

5.1.2. LONG-TERM MODE CHOICE EXPERIMENT

The long-term choice experiments are designed to estimate effects of mobility hubs on car ownership. Car owners could choose to give up their car, and start using shared mobility if it is attractive for them. In the following section, the essential components for the design of the long-term mode choice experiment are explained.

CATEGORIES

In this research, the number of possible monthly kilometres driven by a car is divided into four groups, see table 5.5. In the survey, respondents must indicate the amount of kilometres they drive each month. A choice must be made from one of the four groups. As a result, respondents are presented with choice situations for the long-term choice experiment that resembles their current situation. The monthly distance in the choice situations for which respondents are forced to make a mode choice is presented in table 5.5.

ALTERNATIVES

In the long-term mode choice experiments, people have to choose whether to give up their private car and use mobility hubs for all trips. For this reason, there are only two alternatives for the long-term mode choice experiment, namely the private car and the mobility hub, see table 5.6. In the mobility hub shared e-cars, e-mopeds and e-bikes are offered.

Table 5.5: Classification for the distances in the long-term mode choice experiment.

Group	Monthly travel distance	Choice situation monthly travel distance
1	0 - 1000 kilometre	500 kilometre
2	1000 - 2000 kilometre	1500 kilometre
3	2000 - 3000 kilometre	2500 kilometre
4	3000 kilometre or more	2500 kilometre

Table 5.6: Different alternatives for the long-term mode choice experiment.

	Monthly travelled kilometres		
Alternatives	**500 kilometre**	**1500 kilometre**	**2500 kilometre**
Private car	•	•	•
Mobility hub	•	•	•

ATTRIBUTES AND ATTRIBUTE LEVELS

Chapter 4, provides an overview of various factors that can influence car ownership. The factors that are included as attributes in the long-term choice experiment are operating costs, monthly costs, access time and usage scenario as shown in table 5.7. In the long-term mode choice experiments there are a total of 7 different attributes for the 2 alternatives, see table 5.7.

Table 5.7: Attributes for the two alternatives in the long-term mode choice experiment.

			Alternatives	
Category	**Attributes**		**Private car**	**Mobility hub**
Travel costs	**Operating costs**	Private car	Fixed	
		Shared e-car		•
		Shared e-moped		•
		Shared e-bike		•
	Monthly costs		Fixed	•
Trip time	**Access time**		•	•
Mode preference	**Usage scenario**			•

For the long-term mode choice experiment, only the usage scenario attribute has four attribute levels, while the other attributes have three levels, as explained in section 4.4. The attributes and attribute levels used for the experiment design for the three monthly travel distances can be found in table 5.8.

The operating costs for the private car alternative are fixed and based on an average car, see appendix B.1. The operating costs for the shared mobility alternatives are alternative specific attributes for the mobility hub alternative. The monthly cost of the private car alternative is fixed and is also based on an average car, see appendix B.1. The monthly costs for the mobility hub are based on realistic costs for the use of mobility hubs in the Netherlands, see section 4.4. The operating costs and monthly costs attributes and their attribute levels can be found in table 5.8 for the different monthly travel distances and the two alternatives.

The access time is an alternative specific attribute for both alternatives. The values for the access time attributes of the alternatives are based on realistic walking times to the private car and shared mobility alternatives in the Netherlands, see section 4.4. The access time attributes and their attribute levels can be found in table 5.8 for the different monthly travel distances and the two alternatives.

The mode preference category only consists of the usage scenario attribute. The usage scenario is an alternative specific attribute for the mobility hub alternative. The usage scenario is an alternative specific attribute for the mobility hub alternative. The usage scenario attribute must be realistic and easy to understand for the respondents. For that reason the attribute levels are based on an expectation of how car owners will use the shared modes from the mobility hub, see section 4.4. In the usage scenarios, the use of the different shared mobility modes varies per scenario. The usage scenario attribute and the attribute levels can be found in table 5.8, the meaning of the 4 levels are given in table 4.1.

Table 5.8: Final attribute level values of the long-term mode choice experiment. level 1 is based on a realistic value. On this realistic value, a level 0 and level 2 value are determined. These values represent the lowest attribute value and the highest attribute value respectively. Fixed attributes are displayed as well.

			Level			
Alternative	**Attribute**		**0**	**1**	**2**	**3**
Private car	**Access time [min]**		2	5	8	
	Monthly costs			€123.8		
	Operating costs [€/km]			0.252		
Mobility hub	**Access time [min]**		2	5	8	
	Monthly costs		€10	€30	€50	
	Operating costs [€/km]	Shared e-car	0.058	0.175	0.292	
		Shared e-moped	0.075	0.226	0.377	
		Shared e-bike	0.039	0.118	0.197	
	Usage scenario		0	1	2	3

TYPE OF EXPERIMENTAL DESIGN

The long-term mode choice experiments are labeled experiments, as the alternatives represent actual modes. For efficiency a fractional factorial design is used, resulting in a much smaller number of choice sets compared to a full factorial design. Specifically, an orthogonal fractional factorial design is used, as it allows to estimate all the main effects. Orthogonal fractional factorial design does not require prior values for the parameters. Since the short-term mode choice experiment consists of labeled alternatives with alternative specific attributes, the choice sets are created in a simultaneous way. As a result, there are no within and no between alternative correlations. The choice sets are created with the software program Ngene.

MODEL AND CHOICE SETS

For the long-term mode choice experiment, one model is used to generate the choice sets with Ngene for the three monthly distance categories. As mentioned before, there are 2 alternatives and a total of 7 attributes. For 6 attributes there are 3 levels, and for 1 attribute there are 4 levels. For the choice set there is an orthogonal design with 36 different choice situations. These 36 different choice situations are divided into 6 blocks, each with 6 choice situations. The model for Ngene with the complete choice sets can be found in appendix B.4.2.

5.2. SURVEY DESIGN

The two choice experiments and other questions are implemented in Qualtrics. By using Qualtrics, it is possible to create a survey that is easy to understand, which makes it attractive and pleasant for respondents to complete the survey. The software package Qualtrics is available via TU Delft. Qualtrics makes it relatively easy to create a customised survey. As a result, respondents only get to see questions that apply to their situation. The total time to complete the survey should not exceed 15 minutes. A longer survey can lead to respondents quitting. A pilot survey was first conducted to make sure that the final survey is correct.

5.2.1. PILOT SURVEY

Prior to the launch of the final version of the survey, a number of pilot versions were tested. After each completed survey, the survey was updated after the test respondent's comments. The pilot surveys and the iteration process ensured that the final survey is clear to all respondents. The pilot survey was completed by friends, family and checked by Sweco consultants. In total, fifteen people completed the pilot survey with an average completion time of 15 minutes. The pilot survey has led to better readable paragraphs and clearer questions.

5.2.2. FINAL SURVEY

The pilot survey results in a well-functioning final survey. Figure 5.1 shows the survey outline with the different elements and the routing of the survey. The different elements are discussed below. The complete survey can be seen in appendix C.1.

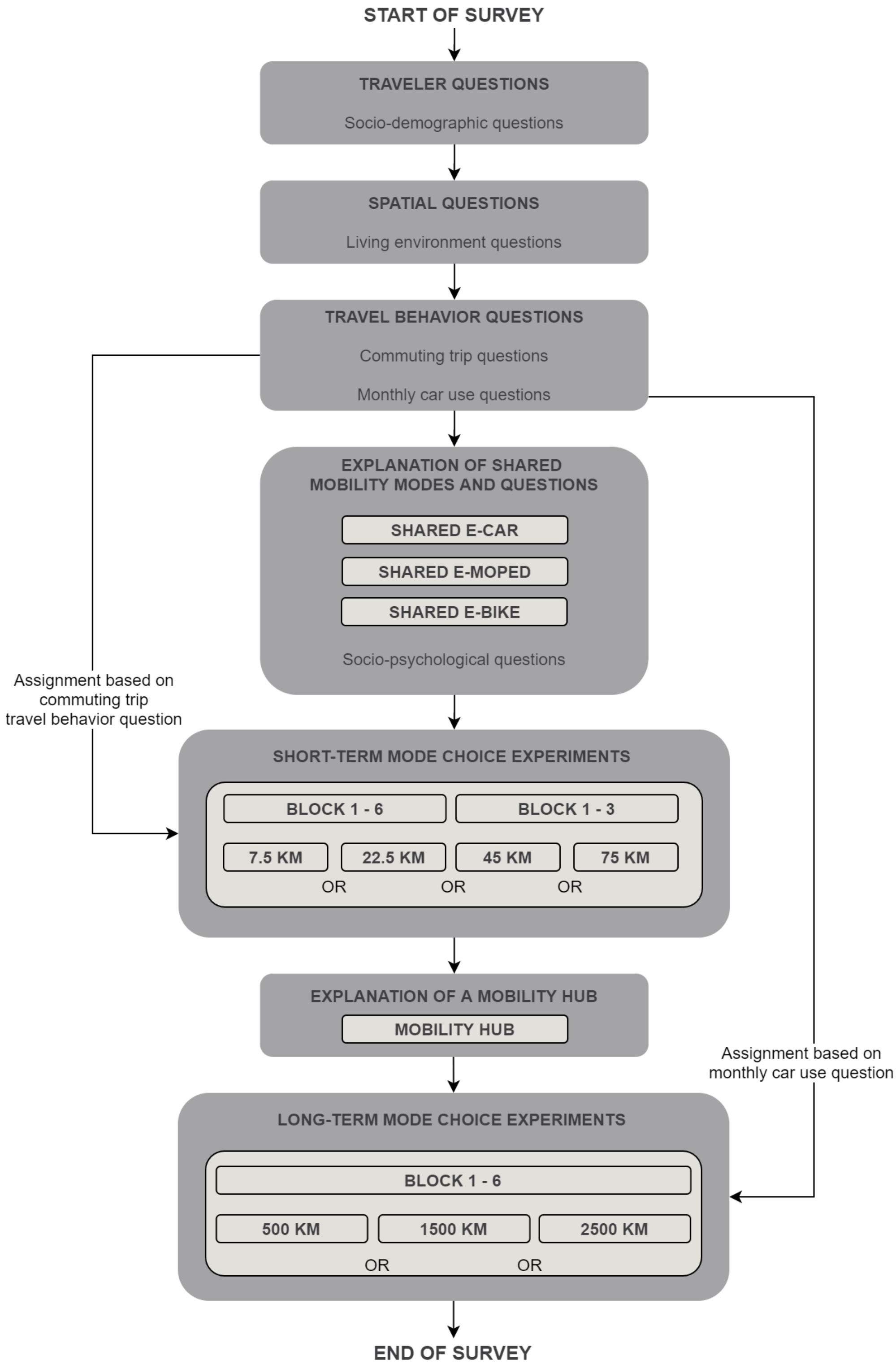


Figure 5.1: Survey outline and routing.

START OF SURVEY

At the start of the survey, the purpose of the survey and the research is explained to the respondents. Since the survey is conducted during the COVID-19 pandemic, the respondents are asked to complete the survey for the situation prior to the COVID-19 pandemic. Furthermore, it is explained to the respondents that the participation is completely anonymous and that the survey can be terminated at any time. The respondents are aware that the data is stored confidentially and completely anonymised and that the data is only used for this research. This explanation is shown in appendix C.1.

TRAVELER QUESTIONS

In the socio-demographic questions the respondents are requested to answer several questions. The questions focus on the age, gender, educational level, income, occupation, household structure and vehicle ownership of the respondent.

SPATIAL QUESTIONS

The spatial questions are composed of questions related to the respondents' living environment. Respondents have to indicate what their immediate living environment looks like, i.e. whether it is a city centre, a suburb, a hinterland or a rural area. The respondents are asked to provide the first four digits of their postal code. This question is optional. Finally, respondents have to indicate whether their house has its own parking space. If not, respondents are asked to indicate the walking time to the car. These questions can be found in the appendix C.1.

TRAVEL BEHAVIOR QUESTIONS

In the travel behaviour questions, several questions are asked. One of the questions affects the distance category for the respondents for the short-term mode choice experiment. The respondents have to indicate the travel distance from home to work. Based on the answer, the respondents are presented with choice questions for the first mode choice experiment, which reasonably fits the respondents' situation, as explained in section 5.1.1. Another question influences the distance category for the respondents for the long-term mode choice experiment. The respondents have to indicate the monthly kilometres they travel by private car. Based on the answer, the respondents are presented with questions for the long-term mode choice experiment that fit the respondents' situation, as explained in section 5.1.2. These questions can be found in the appendix C.1.

EXPLANATION OF SHARED MOBILITY MODES

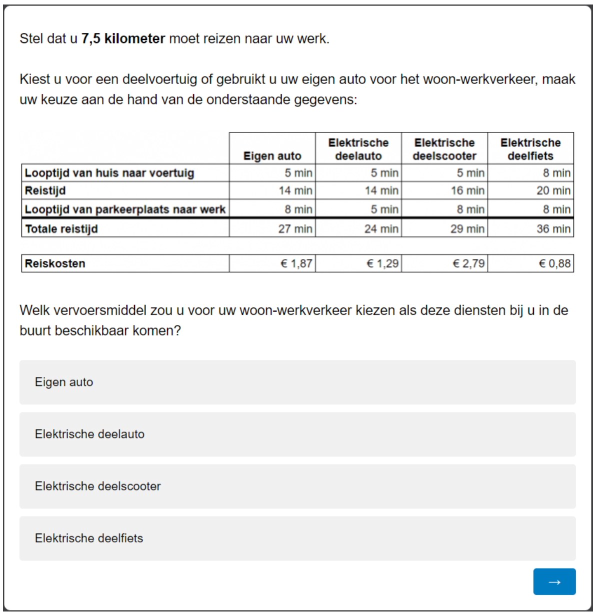
Prior to the first mode choice experiment, respondents are explained what exactly is meant by a shared e-car, shared e-moped and shared e-bike. Followed by the socio-psychological questions, these questions consist of familiarity and experience questions. The respondents are asked whether they are familiar with the shared alternatives, and whether they have already used one of the three shared alternatives. If a respondent indicates that they have used a shared e-car, shared e-moped or shared e-bike in the past, the respondent is asked about the experience. Respondents are requested to give their experience on a Likert scale from 1 to 5, where 1 is very dissatisfied and 5 very satisfied. These questions can be found in the appendix C.1.

SHORT-TERM MODE CHOICE EXPERIMENTS

As described in paragraph 5.1.1, respondents are shown either 6 or 4 choice situations for the short-term mode choice experiment. This depends on the distance the respondent has to travel to work. In the choice situations, respondents have to make a choice among different alternatives for commuting trips. The shared mobility alternatives, from which the respondents can choose in the choice situations, have to be collected and returned to a mobility hub. Hereby it is assumed that the shared mobility alternatives are always available in the mobility hubs and that they can always be returned to a mobility hub. It is clear to the respondents that it concerns commuting trips. An example of a short-term mode choice situation can be seen in figure 5.2 and in appendix C.1.

EXPLANATION OF A MOBILITY HUB

Since mobility hubs are a new concept, many people in the Netherlands do not know what a mobility hub is. Therefore, the survey explains what a mobility hub exactly is. Moreover, it is explained that shared e-cars, shared e-mopeds and shared e-bikes are offered at this location. It is clear to the respondent that it concerns fully electric shared mobility alternatives. The respondents are aware that a monthly fee has to be paid to use the shared mobility services from the mobility hubs. Respondents are also aware that the alternatives always have to be picked up and returned to a mobility hub. An illustration is attached to give respondents a visual impression of a mobility hub. This explanation can be found in appendix C.1.



Stel dat u **7,5 kilometer** moet reizen naar uw werk.

Kiest u voor een deelvoertuig of gebruikt u uw eigen auto voor het woon-werkverkeer, maak uw keuze aan de hand van de onderstaande gegevens:

	Eigen auto	Elektrische deelauto	Elektrische deelscooter	Elektrische deelfiets
Looptijd van huis naar voertuig	5 min	5 min	5 min	8 min
Reistijd	14 min	14 min	16 min	20 min
Looptijd van parkeerplaats naar werk	8 min	5 min	8 min	8 min
Totale reistijd	27 min	24 min	29 min	36 min
Reiskosten	€ 1,87	€ 1,29	€ 2,79	€ 0,88

Welk vervoersmiddel zou u voor uw woon-werkverkeer kiezen als deze diensten bij u in de buurt beschikbaar komen?

Eigen auto

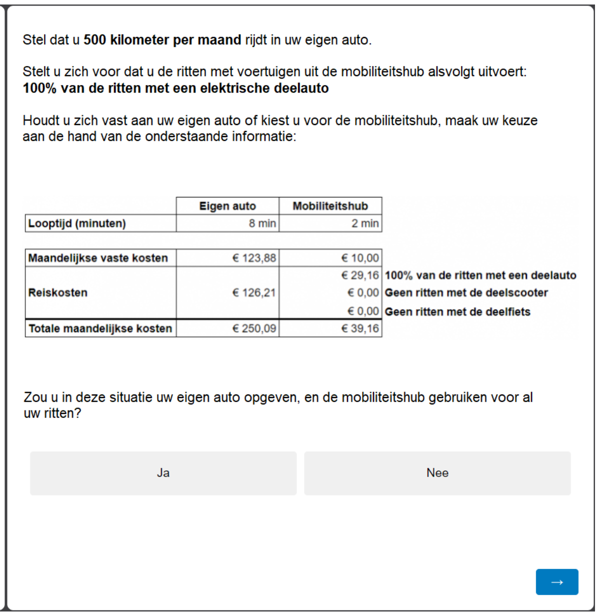
Elektrische deelauto

Elektrische deelscooter

Elektrische deelfiets

→

Figure 5.2: Example of a choice situation for the short-term mode choice experiment.



Stel dat u **500 kilometer per maand** rijdt in uw eigen auto.

Stelt u zich voor dat u de ritten met voertuigen uit de mobiliteitshub alsvolgt uitvoert:
100% van de ritten met een elektrische deelauto

Houdt u zich vast aan uw eigen auto of kiest u voor de mobiliteitshub, maak uw keuze aan de hand van de onderstaande informatie:

	Eigen auto	Mobiliteitshub	
Looptijd (minuten)	8 min	2 min	
Maandelijkse vaste kosten	€ 123,88	€ 10,00	
Reiskosten	€ 126,21	€ 29,16	100% van de ritten met een deelauto
		€ 0,00	Geen ritten met de deelscooter
		€ 0,00	Geen ritten met de deelfiets
Totale maandelijkse kosten	€ 250,09	€ 39,16	

Zou u in deze situatie uw eigen auto opgeven, en de mobiliteitshub gebruiken voor al uw ritten?

Ja | Nee

→

Figure 5.3: Example of a choice situation for the long-term mode choice experiment.

LONG-TERM MODE CHOICE EXPERIMENTS

As described in paragraph 5.1.1, respondents will have to make a choice for 6 different choice situations for the long-term mode choice experiment. For these 6 situations the respondents have to indicate whether to give up their private car and use vehicles from the mobility hub for all trips. An example can be seen in figure 5.3 and in appendix C.1.

END OF SURVEY

At the end of the survey it is possible to submit feedback. The respondents who are interested in the research can also leave their e-mail address. The research can then be shared with the interested respondents after the research is completed. This can be found in appendix C.1.

6

RESULTS

This chapter provides insight into the sample statistics and the results of the models of the advent of mobility hubs in both the short and long term. First, section 6.1 presents the descriptive statistics with the representativeness of the sample, the use of shared mobility of the respondents in the sample and the choice distributions. Section 6.2 discusses the results of the models and the interpretation of these models is elaborated in section 6.3. Section 6.4 discusses the key findings.

6.1. DESCRIPTIVE STATISTICS

The survey was online between 1 October 2020 and 19 November 2020. The survey was taken offline after no respondents participated in the experiments for a longer period of time. A total of 773 respondents started the survey, of which 709 eventually completed it. 533 respondents started the survey via the anonymous link, and 176 via the QR code on the flyer. Finally, the respondents that did not have a car, had a lease car or were not willing to buy a car within 12 months had to be removed from the sample. As described in the scope in section 1.1, the sample for this research only requires car owners. As a result, the sample used for this research contains 574 respondents. The average time required to complete the survey was around 16 minutes.

6.1.1. REPRESENTATIVESNESS OF THE SAMPLE

The calculations of the minimum number of respondents required for the different stated choice experiments are included in appendix D.1. Since this is a guideline, it is not a hard requirement that is necessary for reliable results. The number of respondents for the different categories of the two stated choice experiments can be found in tables 6.1 and 6.2. The minimum number of respondents according to the guideline was not found for all distances.

Table 6.1: The minimum required and the number of respondents obtained in the short-term mode choice experiment.

	7.5 kilometre	22.5 kilometre	45 kilometre	75 kilometre
Minimum required respondents	63	63	188	188
Number of respondents in the sample	153	121	131	90

Table 6.2: The minimum required and the number of respondents obtained in the long-term mode choice experiment.

	500 kilometre	1500 kilometre	2500 kilometre
Minimum required respondents	167	167	167
Number of respondents in the sample	253	190	131

PLACES OF RESIDENCE OF THE RESPONDENTS

In the survey, respondents were asked, among other things, what the postcode of their home address is. Although they were asked for the PC4, which is only the numerical part of the Dutch postcode, the respondents were not very willing to provide it. 266 of the 574 respondents provided the postcode. The postcodes of the

Figure 6.1: Places of residence of the sample respondents.

respondents were mapped with Google Maps, the result can be seen in figure 6.1. Most of the respondents live in the Randstad area. Respondents mainly live in the provinces of South Holland, North Holland and Utrecht. A small number of respondents are from outside these three provinces.

CHARACTERISTICS OF THE RESPONDENTS

Due to the scope of this research and the way the respondents were approached, the sample is not representative for the Dutch population but more for people from urban areas and mainly from the Randstad. The socio-demographic characteristics of the sample are compared with the population of the Randstad and the Dutch population. This provides insight into the representativeness of the sample compared to the population of the Randstad or the Dutch population. The CBS sometimes has socio-demographic data available at city level and sometimes only at national level. For the sake of simplicity, the population of the Randstad in this research is represented by Amsterdam, Rotterdam, The Hague and Utrecht. The sample was compared to the Dutch population when no data was available regarding the four largest cities in the Randstad. For some characteristics, there was no data available for either the Randstad or the Netherlands and therefore no comparison was made. The socio-demographic data of the sample were compared with the population aged 18 and older. The reason for this was to be able to properly describe and compare the sample with the population of the Randstad or the Dutch population. As the sample is not representative for the Dutch population but more for the Randstad, it can lead to underestimations and overestimations compared to the Dutch population.

The ratio of men to women in the sample is almost equal to that in the population in the Randstad and the Dutch population [CBS, 2020a,d]. There were two cases in the sample who refused to disclose their gender. The CBS has complete insight into the gender of the population in the Randstad and in the Netherlands, hence table 6.3 only provides insight into the gender distributions for both populations [CBS, 2020a,d]. For gender, the sample resembles the population from the Randstad better than the entire Dutch population, see appendix D.3.1.

The sample contains many young people aged between 26 and 45 and relatively few older people aged 66 and over. For age, the sample resembles the population from the Randstad better than the entire Dutch population, see appendix D.3.2. Young people predominate in the group of early adopters, see section 2.3.3. This group is more inclined to make use of innovation and shared mobility services among other things. As a result, the willingness to use shared mobility in the sample may differ from the population from the Randstad. This may lead to an overestimation of the willingness to use shared mobility services.

The sample contains many higher educated people, and few lower educated people. Higher educated people often earn more and are more inclined to use the car [Pickery, 2005]. On the other hand, higher educated people are often more inclined to shared mobility than lower educated people, see section 2.3.3).

Table 6.3: Descriptive statistics of the sample for gender and age.

Variable	Category	Percentage sample	Percentage Randstad (CBS [2020a])	Percentage NL (CBS [2020a])
Gender	Men	48.6%	49.5%	49.7%
	Woman	51.0%	50.5%	50.3%
	Different	0.3%	0.0%	0.0%
Age	18-25	6.1%	14.8%	12.4%
	26-35	22.1%	23.2%	15.7%
	36-45	24.0%	16.9%	14.6%
	46-55	20.9%	16.0%	17.7%
	56-65	18.5%	13.1%	16.3%
	66-75	5.6%	9.2%	13.2%
	75+	2.8%	6.9%	10.2%

The sample contains a lot of high earners. There may be economic reasons to give up the private car. High earners may have less economic interest in giving up their private car. A high income has a positive relationship with car use and car ownership [De Witte et al., 2013, Vasconcellos, 2005]. This may explain the high car ownership in the sample, see table 6.6. Since the sample contains many high earners, it is possible that the willingness to give up the car may differ to the Dutch population. This may lead to an underestimation of the willingness to use shared mobility services compared to the Dutch population.

Table 6.4: Descriptive statistics of the sample for educational level and income level.

Variable	Category	Percentage sample	Percentage NL (CBS [2020e], OCW [2019])
Education level	Primary education	0.3%	8.6%
	VMBO, HAVO-, VWO-onderbouw, MBO1	1.0%	19.3%
	HAVO, VWO, MBO2-4	12.2%	38.1%
	HBO-, University-bachelor	36.7%	20.6%
	HBO-, University-master,doctor	49.2%	11.9%
	Unkown	0.5%	1.5%
Income level	0 - 36000	20.4%	76.3%
	36.000 - 72.000	47.9%	22.5%
	72.000 or more	27.7%	1.2%
	Unkown	4.0%	

The sample includes mostly paid employees, as well as a large group of self-employed people. Despite the fact that the sample consists of many young people, the sample contains relatively few students. The sample contains almost three quarters of full-time employees and almost a quarter of part-time employees. This may partly explain the high income per household. People who work full time often earn more than part-time workers. Since part-time workers are more inclined to use the car, the use of shared mobility might be overestimated, see section 2.4.2.

The sample contains relatively many multi-person households, whereas the sample consists of a small number of single-person households compared to the Randstad population. The size and structure of the household affects car ownership, see section 2.4.2). This may partly explain why the sample contains many more cars per household compared to the actual situation[1], see table 6.6.

There are between 12.5 and 15.6 million parking spaces, of which there are 8.9 million public parking spaces [ECORYS, 2006]. Based on this low worst-case scenario percentages and high worst-case scenario percentages were calculated, as can be seen in table 6.7. The sample deviates from the estimate by ECORYS. Because in the experiments the respondents with their own parking space were presented with a choice of situations in which they did not have their own parking space, a bias may occur for the walking times to own cars or shared modes.

[1] Cars in household is normalized to 1 car. The 0 cars households are excluded (see appendix D.4)

Table 6.5: Descriptive statistics of the sample for working status and occupation.

Variable	Category	Percentage sample	Percentage NL (CBS [2020c])
Working status	Self-employed	21.6%	
	Salaried employee	63.6%	
	Incapacitated	0.2%	
	Unemployed or job seeking	1.7%	
	Retired or early retirement	5.6%	
	Studying	4.7%	
	Housewife or houseman	1.4%	
	Other	1.2%	
	Unknown	0.0%	
Occupation	Part time	23.7%	49.4%
	Full time	76.3%	50.6%

Table 6.6: Descriptive statistics of the sample for household size and cars in household.

Variable	Category	Percentage sample	Percentage Randstad (CBS [2019c])	Percentage NL (CBS [2019c])
Household size	1 person	7.3%	51.0%	38.5%
	2 persons	41.3%	26.1%	32.6%
	3 persons	20.2%	10.1%	11.7%
	4 persons	21.8%	8.5%	12.0%
	5 persons or more	9.4%	4.3%	5.1%
Cars in the household	1	31.0%		68.5%
	2	59.1%		26.0%
	3 or more	9.9%		5.5%

In the survey, respondents were asked about the living environment. The sample shows that the largest group of respondents lives in a suburb, followed by the hinterland and then by city centre residents. A small group of respondents indicated that they lived in a rural area. In the Randstad area, the distinction between hinterlands and rural areas is very thin. Therefore, in the rest of this research, hinterlands and rural areas are merged into only rural areas.

Table 6.7: Descriptive statistics of the sample for possession of own parking space and living environment.

Variable	Category	Percentage sample	Percentage NL (ECORYS [2006]) worst-case	Percentage NL (ECORYS [2006]) worst-case
In possession of own parking space	Yes	51.2%	28.8%	43.0%
	No	48.8%	71.2%	57.0%
Living environment	City centre	20.0%		
	Suburban area	39.9%		
	Hinterlands	30.2%		
	Rural area	9.9%		

6.1.2. SHARED MOBILITY USAGE AND EVALUATION

Of the three types of shared mobility systems that appeared as alternatives in the experiments, the sample shows that shared bikes were the most often used by the respondents as shown in table 6.8. Almost half of all 574 respondents in the sample ever used shared bikes. After the shared bike, the shared moped is the most often used and few respondents have ever used a shared car. However, only a very small group has never heard of shared cars, while more respondents indicate that they have never heard of shared mopeds or shared bikes.

Table 6.8: Usage history of the various shared mobility modes in percentages of the respondents. The number in brackets indicates how many times that alternative was chosen.

	Shared car	Shared moped	Shared bike
I have used	15.8% (91)	26.3% (151)	48.8% (280)
I have heard of it but not used	82.6% (474)	66.2% (380)	46.3% (266)
I have never heard of	1.6% (9)	7.5% (43)	4.9% (28)

Respondents were asked about their overall experience if they indicated that they had ever used a shared mode. The shared moped is best assessed by the respondents in the sample, see tables 6.9 and D.3. After that, the shared car is rated the best, despite the small percentage of users in the sample. The shared bike was rated lowest. However, the scores are close to each other, and the ratings for shared cars and shared mopeds are based on fewer respondents than for the shared bike.

Table 6.9: Evaluation of the shared modes in percentages of the respondents. The number in brackets indicates how many times that alternative was chosen.

	Shared car	Shared moped	Shared bike
Very dissatisfied	0.0% (0)	0.0% (0)	1.4% (4)
Dissatisfied	1.1% (1)	0.7% (1)	1.4% (4)
Neutral	8.8% (8)	5.3% (8)	16.1% (45)
Satisfied	39.6% (36)	37.1% (56)	36.1% (101)
Very satisfied	50.5% (46)	57.0% (86)	45.0% (126)

6.1.3. CHOICE DISTRIBUTIONS

To examine the popularity and preferences of the respondents, one can look at the absolute numbers of the answers and the choice distributions. First general insight into the choices of the various alternatives can be obtained using the choice distributions of the choices made in the choice experiments. However, the choices made in the experiments depend strongly on the attribute level values in the choice situations, which is why the choice distributions can only be used to observe trends in the choice data.

SHORT-TERM MODE CHOICE EXPERIMENT

For the short-term mode choice experiment, it can be seen that for the various distances a different number of total choices were made, see table 6.10. The shared e-car is for all four distances the most chosen for the different choice situations, see table 6.10. As the distance increases, the shared e-car is chosen more often in percentage terms per distance. For distances of 7.5 and 22.5 kilometres, the shared e-car is chosen more often than the private car, while the shares for both the shared moped and the shared bicycle are substantially small. The same applies to the distances of 45 kilometres and 75 kilometres. The shared e-car is chosen more often than the private car.

Table 6.10: Choice distributions for the four work-related distance categories in the short-term mode choice experiment. The number in brackets indicates how many times that alternative was chosen.

Alternative	7.5 km	22.5 km	45 km	75 km
Private car	34.2% (314)	44.6% (323)	42.1% (226)	36.9% (133)
Shared e-car	35.2% (323)	51.5% (373)	56.9% (298)	63.1% (227)
Shared e-moped	13.4% (123)	2.5% (18)		
Shared e-bike	17.2% (158)	1.5% (11)		

LONG-TERM MODE CHOICE EXPERIMENT

For the long-term mode choice experiment, it can be seen that for the different monthly distances a different number of total choices were made, see table 6.11. Based on the choice distributions for the long-term mode choice experiment, an increasing trend is observed for the private car, see table 6.11. This trend seems to indicate that the popularity of the private car increases with the monthly travel distance. However, this is a weak trend. The share increases only slightly with increasing monthly travel distance.

Table 6.11: Choice distributions for the three monthly travel distance categories in the long-term mode choice experiment. The number in brackets indicates how many times that alternative was chosen.

Alternative	500 km	1500 km	2500 km
Private car	50.2% (762)	51.4% (586)	53.7% (422)
Mobility hub	49.8% (756)	48.6% (554)	46.3% (364)

6.1.4. CONCLUSION ON SAMPLE

The sample for this research is described in section 6.1 on descriptive statistics. The respondents are mainly from South Holland, North Holland and Utrecht. It therefore seems plausible that the sample is representative of people from the Randstad. The sample contains many young people, with a higher level of education and a higher income. The respondents own several cars in the household. A good mix of respondents was found who live in a city centre, suburban area and rural area. Most respondents have used the shared bike and least the shared car. Respondents rated the shared moped best, followed by the shared car while the shared e-bike was rated worst. The choice distributions show that respondents opted, under certain conditions, for shared mobility alternatives instead of the private car for work-related trips. Moreover, respondents opted, under certain conditions, to give up the least used private car and to use shared mobility services offered in mobility hubs for all trips.

6.2. MODEL RESULTS

Discrete choice modelling was used to estimate the effects of the various variables in the choice experiments. In this research, only the MNL model and an extended MNL model were used, as explained in chapter 3.3.2. The data from the sample were structured using Microsoft Excel, allowing the modelling to be done using BisonBiogeme [Bierlaire, 2009].

6.2.1. MODELLING APPROACH

Two types of models are used in this research for both experiments. These are base multinomial logit models and extended multinomial logit models. First, the base MNL models are estimated, after which the extended MNL models are estimated. The base MNL model consists of the main parameters that are attributes in the stated choice experiment. Furthermore, each alternative has an alternative specific constant, but for one alternative the ASC is set to zero which is the reference alternative. The ASC are relative utility differences compared to the ASC of the reference alternative. For a more accurate estimate of how Randstad residents from defined residential areas respond to shared mobility and whether these people are willing to give up their least used private car, variables were added. Specifically, these are dummy variables. Dummy variables for living environment and the number of cars in a household were added to the base MNL model, see appendix D.4. The result is the extended multinomial logit model.

BASE MULTINOMIAL LOGIT MODELS

The base MNL models consist only of alternative specific parameters and alternative specific constants for the different alternatives. The utility functions for the short-term mode choice experiment are shown in equations 6.1-6.4, and for the long-term mode choice experiment in equations 6.5-6.6.

Short-term mode choice experiment

The utility model for the short-term mode choice experiment is shown in equations 6.1-6.4. The reference alternative here is the private car, since the ASC for this alternative is set to zero it is omitted from utility function 6.1.

$$U_{car} = \beta_{car.AD} \cdot AD_{car} + \beta_{car.ED} \cdot ED_{car} + \epsilon \tag{6.1}$$

$$U_{ecar} = ASC_{ecar.\#km} + \beta_{ecar.AD} \cdot AD_{ecar} + \beta_{ecar.ED} \cdot ED_{ecar} + \beta_{ecar.TC} \cdot TC_{ecar} + \epsilon \tag{6.2}$$

$$\begin{aligned} U_{emoped} = {} & ASC_{emoped.\#km} + \beta_{emoped.AD} \cdot AD_{emoped} \\ & + \beta_{emoped.ED} \cdot ED_{emoped} + \beta_{emoped.TC} \cdot TC_{emoped} + \epsilon \end{aligned} \tag{6.3}$$

$$\begin{aligned} U_{ebike} = {} & ASC_{ebike.\#km} + \beta_{ebike.AD} \cdot AD_{ebike} \\ & + \beta_{ebike.ED} \cdot ED_{ebike} + \beta_{ebike.TC} \cdot TC_{ebike} + \epsilon \end{aligned} \tag{6.4}$$

Where,
U_{car} is the utility of the private car alt.
U_{ecar} is the utility of the shared e-car alt.
U_{emoped} is the utility of the shared e-moped alt.
U_{ebike} is the utility of the shared e-bike alt.

$ASC_{ecar.\#km}$ is the ASC for the shared e-car alt. for distances of 7.5, 22.5, 45 or 75 km
$ASC_{emoped.\#km}$ is the ASC for the shared e-moped alt. for distances of 7.5 or 22.5 km
$ASC_{ebike.\#km}$ is the ASC for the shared e-bike alt. for distances of 7.5 or 22.5 km

$\beta_{car.AD}$ is the alt. spec. parameter for attr. access time for the private car alt.
$\beta_{ecar.AD}$ is the alt. spec. parameter for attr. access time for the shared e-car alt.
$\beta_{emoped.AD}$ is the alt. spec. parameter for attr. access time for the shared e-moped alt.
$\beta_{ebike.AD}$ is the alt. spec. parameter for attr. access time for the shared e-bike alt.

$\beta_{car.ED}$ is the alt. spec. parameter for attr. egress time for the private car alt.
$\beta_{ecar.ED}$ is the alt. spec. parameter for attr. egress time for the shared e-car alt.
$\beta_{emoped.ED}$ is the alt. spec. parameter for attr. egress time for the shared e-moped alt.
$\beta_{ebike.ED}$ is the alt. spec. parameter for attr. egress time for the shared e-bike alt.

$\beta_{ecar.TC}$ is the alt. spec. parameter for attr. travel cost for the shared e-car alt.
$\beta_{emoped.TC}$ is the alt. spec. parameter for attr. travel cost for the shared e-moped alt.
$\beta_{ebike.TC}$ is the alt. spec. parameter for attr. travel cost for the shared e-bike alt.

ϵ is the random error component

Long-term mode choice experiment
The utility model for the long-term mode choice experiment is shown in equations 6.5 and 6.6. The reference alternative here is the mobility hub, since the alternative specific constant for this alternative is set to zero it is omitted from utility function 6.6. In utility function 6.6, the scenario attribute consists of 3 different parameters, since the usage scenario is a categorical variable. A dummy variable is used for the scenario attribute, see appendix D.4.

$$U_{car} = ASC_{car.\#km} + \beta_{car.AD} \cdot AD_{car} + \epsilon \tag{6.5}$$

$$\begin{aligned} U_{ehub} = \beta_{ehub.AD} \cdot AD_{ehub} + \beta_{ehub.SF} \cdot SF_{ehub} \\ + \beta_{ehub.ecar.TC} \cdot TC_{ehub.ecar} + \beta_{ehub.emoped.TC} \cdot TC_{ehub.emoped} \\ + \beta_{ehub.ebike.TC} \cdot TC_{ehub.ebike} + \beta_{ehub.Scenario.low} \cdot scenario_{low} \\ + \beta_{ehub.Scenario.mid} \cdot scenario_{mid} + \beta_{ehub.Scenario.high} \cdot scenario_{high} + \epsilon \end{aligned} \tag{6.6}$$

Where,
U_{car} is the utility of the private car alt.
U_{ehub} is the utility of the e-hub alt.

$ASC_{car.\#km}$ is the ASC for the private car alt. for distances of 500, 1500 or 2500 km

$\beta_{car.AD}$ is the alt. spec. parameter for attr. access time for the private car alt.
$\beta_{ehub.AD}$ is the alt. spec. parameter for attr. access time for the e-hub alt.

$\beta_{ehub.SF}$ is the alt. spec. specific parameter for attr. subscription fee for the e-hub alt.
$\beta_{ehub.ecar.TC}$ is the alt. spec. parameter for attr. operating cost for the shared e-car for the e-hub alt.
$\beta_{ehub.emoped.TC}$ is the alt. spec. parameter for attr. operating cost for the shared e-moped for the e-hub alt.
$\beta_{ehub.ebike.TC}$ is the alt. spec. parameter for attr. operating cost for the shared e-bike for the e-hub alt.

$\beta_{ehub.Scenario.low}$ is the alt. spec. parameter for attr. scenario low for the e-hub alt.
$\beta_{ehub.Scenario.mid}$ is the alt. spec. parameter for attr. scenario medium for e-hub alt.
$\beta_{ehub.Scenario.high}$ is the alt. spec. parameter for attr. scenario high for the e-hub alt.

ϵ is the random error component

EXTENDED MULTINOMIAL LOGIT MODELS

The extended multinomial logit models are the base MNL models to which variables for the type of living environment and the number of cars in a household are added. In order to examine to which extent the socio-demographics influence the choice, the interaction effects of the socio-demographic variables have to be estimated with the alternative specific constant. In this way, it can be estimated to what extent the number of cars in a household or the living environment affects the preference for the various alternatives [Molin and Timmermans, 2010]. For both variables dummy variables were used, see appendix D.4. The reason for adding only these socio-demographic variables is explained in section 6.2.1.The result is presented for the short-term mode choice experiment in equations 6.7-6.10 and for the long-term mode choice experiment in 6.11-6.12.

Short-term mode choice experiment

The utility model for the short-term mode choice experiment is shown in equations 6.7-6.10. The dummy variables of living environment and the number of cars in the household are presented in utility functions 6.8-6.10, for both characteristics there are two different parameters, see appendix D.4.

$$U_{car} = \beta_{car.AD} \cdot AD_{car} + \beta_{car.ED} \cdot ED_{car} + \epsilon \tag{6.7}$$

$$\begin{aligned} U_{ecar} = {} & ASC_{ecar.\#km} + \beta_{ecar.AD} \cdot AD_{ecar} + \beta_{ecar.ED} \cdot ED_{ecar} + \beta_{ecar.TC} \cdot TC_{ecar} \\ & + \beta_{ecar_{LE.Center}} \cdot LE_{Center} + \beta_{ecar_{LE.Suburban}} \cdot LE_{Suburban} \\ & + \beta_{ecar_{Cars.One}} \cdot Cars_{One} + \beta_{ecar_{Cars.Two}} \cdot Cars_{Two} + \epsilon \end{aligned} \tag{6.8}$$

$$\begin{aligned} U_{emoped} = {} & ASC_{emoped.\#km} + \beta_{emoped.AD} \cdot AD_{emoped} + \beta_{emoped.ED} \cdot ED_{emoped} \\ & + \beta_{emoped.TC} \cdot TC_{emoped} \\ & + \beta_{emoped_{LE.Center}} \cdot LE_{Center} + \beta_{emoped_{LE.Suburban}} \cdot LE_{Suburban} \\ & + \beta_{emoped_{Cars.One}} \cdot Cars_{One} + \beta_{emoped_{Cars.Two}} \cdot Cars_{Two} + \epsilon \end{aligned} \tag{6.9}$$

$$\begin{aligned} U_{ebike} = {} & ASC_{ebike.\#km} + \beta_{ebike.AD} \cdot AD_{ebike} + \beta_{ebike.ED} \cdot ED_{ebike} \\ & + \beta_{ebike.TC} \cdot TC_{ebike} \\ & + \beta_{ebikeLE.Center} \cdot LE_{Center} + \beta_{ebike_{LE.Suburban}} \cdot LE_{Suburban} \\ & + \beta_{ebike_{Cars.One}} \cdot Cars_{One} + \beta_{ebike_{Cars.Two}} \cdot Cars_{Two} + \epsilon \end{aligned} \tag{6.10}$$

Where,
$\beta_{\#_{LE.Center}}$ is alt. spec. parameter for variable living env. center for alternative shared e-car, e-moped or e-bike
$\beta_{\#_{LE.Suburb}}$ is alt. spec. parameter for variable living env. suburb for the shared e-car, e-moped or e-bike alts.
$\beta_{\#_{Cars.One}}$ is alt. spec. parameter for one car in household for the shared e-car, e-moped or e-bike alts.
$\beta_{\#_{Cars.Two}}$ is alt. spec. parameter for two cars in household for the shared e-car, e-moped or e-bike alts.

Short-term mode choice experiment

The utility model for the long-term mode choice experiment is shown in equations 6.11 and 6.12. The dummy variables of living environment and the number of cars in the household are presented in utility function 6.11, for both characteristics there are two different parameters, see appendix D.4.

$$\begin{aligned} U_{car} = {} & ASC_{car.\#km} + \beta_{car.AD} \cdot AD_{car} + \beta_{car_{LE.Center}} \cdot LE_{Center} + \beta_{car_{LE.Suburban}} \cdot LE_{Suburban} \\ & + \beta_{car_{Cars.One}} \cdot Cars_{One} + \beta_{car_{Cars.Two}} \cdot Cars_{Two} + \epsilon \end{aligned} \tag{6.11}$$

$$\begin{aligned} U_{ehub} = {} & \beta_{ehub.AD} \cdot AD_{ehub} + \beta_{ehub.SF} \cdot SF_{ehub} \\ & + \beta_{ehub.ecar.TC} \cdot TC_{ehub.ecar} + \beta_{ehub.emoped.TC} \cdot TC_{ehub.emoped} \\ & + \beta_{ehub.ebike.TC} \cdot TC_{ehub.ebike} + \beta_{ehub.Scenario.low} \cdot scenario_{low} \\ & + \beta_{ehub.Scenario.mid} \cdot scenario_{mid} + \beta_{ehub.Scenario.high} \cdot scenario_{high} + \epsilon \end{aligned} \tag{6.12}$$

Where,
$\beta_{car_{LE.Center}}$ is alt. spec. parameter for variable living env. center for the private car alt.

$\beta car_{LE.Suburb}$ is alt. spec. parameter for variable living env. suburb for the private car alt.
$\beta car_{Cars.One}$ is alt. spec. parameter for one car in household for the private car alt.
$\beta car_{Cars.Two}$ is alt. spec. parameter for two cars in household for the private car alt.

6.2.2. MODEL FIT AND VALIDATION

For the assessment of the performance of the models, two methods were used, see table 6.12. First, the Likelihood Ratio Test Statistic, for all distance categories of both experiments the extended MNL models perform better. Moreover, the values of the adjusted rho-squared also increase from the base MNL models to the extended MNL models. There is an improvement in the explanatory power from base MNL to extended MNL.

Table 6.12: Performance of the estimated models.

Experiment	Distance	Model	Parameters	Final LL	Rho-square	Adjusted rho-square
Short-term mode choice experiment	**7.5 km**	**Base MNL**	14	-842.546	0.338	0.327
		Extended MNL	26	-812.057	0.361	0.341
	22.5 km	**Base MNL**	14	-455.504	0.547	0.533
		Extended MNL	23	-439.594	0.563	0.540
	45 km	**Base MNL**	6	-214.934	0.407	0.391
		Extended MNL	10	-212.946	0.413	0.394
	75 km	**Base MNL**	6	-134.977	0.458	0.433
		Extended MNL	10	-131.770	0.470	0.439
Long-term mode choice experiment	**500 km**	**Base MNL**	10	-901.540	0.143	0.133
		Extended MNL	14	-885.003	0.158	0.145
	1500 km	**Base MNL**	10	-623.884	0.210	0.197
		Extended MNL	14	-617.820	0.217	0.200
	2500 km	**Base MNL**	10	-376.742	0.302	0.284
		Extended MNL	14	-369.134	0.316	0.290

The adjusted rho-square for the models of the different distances of the short-term mode choice experiment are quite high. This indicates that the model explains to data well. This may, however, be a consequence of the attribute levels in the stated choice experiment. The attribute levels were quite extreme. This may lead to situations where the choice was easy for the respondents.

6.3. MODEL INTERPRETATION

The final parameter estimates provide insight into the effects of the attributes and socio-demographic characteristics on the choice of respondents. First, the short-term model is discussed, followed by the long-term model. For the interpretation of the models, only trends in which the difference between two variables found are significant at a confidence interval of at least 90% or stronger are identified. Moreover, the interpretation between the differences of two or more variables is based on the assumption that the trends are only valid if the other factors are equal. Since this research is an exploratory study, the non-significant variables are included in the rest of the research. The objective of this research is to get an idea of the short term effects of mobility hubs in the built environment and not the exact demand for shared mobility services in the future. In this research, the relationship is explored between these variables and a certain behaviour.

6.3.1. SHORT-TERM MODEL

In table 6.13, the estimated parameter values are listed for the short-term model. The table shows the significance levels of the parameters for the confidence levels of 99%, 95% and 90%. On these confidence levels, the parameters have the expected sign.

Using the dummy coding, as shown in table D.14, causes errors for the parameter estimations for the commuting trip of 22.5 kilometres. There is a high correlation between the two variables for the dummy variable for the number of cars per household. A dummy variable with two levels, see table D.15, does not cause any problems. Therefore, for a commuting distance of 22.5 kilometres, a dummy variable with two levels is used.

Table 6.13: Parameter estimations of extended MNL models for short-term mode choice experiment. *** indicates significant on a 99% confidence level, ** indicates significant on a 95% confidence level, * indicates significant on a 90% confidence level.

	7.5 km					22.5 km					45 km					75 km				
Name	**Value**	**Robust Std err**	**Robust t-test**	**p-value**		**Value**	**Robust Std err**	**Robust t-test**	**p-value**		**Value**	**Robust Std err**	**Robust t-test**	**p-value**		**Value**	**Robust Std err**	**Robust t-test**	**p-value**	
Private car (Reference Alternative)																				
BETA_CAR_AD	-0.24	0.0358	-6.69	0	***	-0.109	0.0382	-2.85	0	***	-0.205	0.0476	-4.3	0	***	-0.113	0.0662	-1.71	0.09	*
BETA_CAR_ED	-0.185	0.0354	-5.23	0	***	-0.165	0.0398	-4.15	0	***	-0.158	0.0706	-2.24	0.03	**	-0.261	0.107	-2.44	0.01	**
E-car																				
ASC_ECAR	0.658	0.503	1.31	0.19		2.11	0.478	4.41	0	***	3.74	0.81	4.62	0	***	4.41	1.15	3.82	0	***
BETA_ECAR_AD	-0.0849	0.0373	-2.28	0.02	**	-0.0829	0.0401	-2.07	0.04	**	-0.153	0.0465	-3.28	0	***	-0.155	0.0631	-2.46	0.01	**
BETA_ECAR_ED	-0.168	0.0371	-4.52	0	***	-0.0743	0.0396	-1.88	0.06	*	-0.209	0.0494	-4.22	0	***	-0.169	0.0694	-2.43	0.01	**
BETA_ECAR_TC	-17.8	1.14	-15.64	0	***	-16.6	1.19	-14.01	0	***	-19.9	1.88	-10.55	0	***	-23.4	2.95	-7.94	0	***
BETA_ECAR_CARS_ONE	0.979	0.365	2.68	0.01	***	-0.151	0.234	-0.65	0.52		-0.123	0.54	-0.23	0.82		0.612	0.575	1.06	0.29	
BETA_ECAR_CARS_TWO	1.38	0.342	4.04	0	***						-0.101	0.507	-0.2	0.84		0.933	0.508	1.84	0.07	*
BETA_ECAR_LIVING_CENTER	0.832	0.295	2.82	0	***	0.631	0.259	2.43	0.01	**	0.247	0.343	0.72	0.47		-0.277	0.468	-0.59	0.55	
BETA_ECAR_LIVING_SUBURB	0.406	0.234	1.74	0.08	*	0.708	0.242	2.92	0	***	0.533	0.266	2.01	0.04	**	-0.407	0.342	-1.19	0.23	
E-moped																				
ASC_EMOPED	-0.565	0.672	-0.84	0.4		-2.35	1.11	-2.11	0.03	**										
BETA_EMOPED_AD	-0.259	0.049	-5.28	0	***	-0.0644	0.0901	-0.72	0.47											
BETA_EMOPED_ED	-0.194	0.0504	-3.84	0	***	-0.24	0.115	-2.09	0.04	**										
BETA_EMOPED_TC	-12.3	1.41	-8.73	0	***	-7.63	2.87	-2.66	0.01	***										
BETA_EMOPED_CARS_ONE	1.84	0.5	3.69	0	***	0.557	0.436	1.28	0.2											
BETA_EMOPED_CARS_TWO	1.68	0.471	3.57	0	***															
BETA_EMOPED_LIVING_CENTER	0.585	0.363	1.61	0.11		1.54	0.574	2.68	0.01	***										
BETA_EMOPED_LIVING_SUBURB	0.331	0.288	1.15	0.25		-0.461	0.884	-0.52	0.6											
E-bike																				
ASC_EBIKE	0.384	0.53	0.72	0.47		-0.501	2.01	-0.25	0.8											
BETA_EBIKE_AD	-0.337	0.0473	-7.12	0	***	-0.383	0.17	-2.25	0.02	**										
BETA_EBIKE_ED	-0.272	0.0462	-5.88	0	***	-0.671	0.243	-2.76	0.01	***										
BETA_EBIKE_TC	-14	1.75	-8	0	***	-6.17	6.15	-1	0.32											
BETA_EBIKE_CARS_ONE	0.815	0.393	2.08	0.04	**	-1.87	1.04	-1.81	0.07	*										
BETA_EBIKE_CARS_TWO	1.34	0.354	3.78	0	***															
BETA_EBIKE_LIVING_CENTER	0.0905	0.348	0.26	0.8		1.6	0.855	1.87	0.06	*										
BETA_EBIKE_LIVING_SUBURB	0.244	0.251	0.97	0.33		0.803	0.894	0.9	0.37											

ALTERNATIVE SPECIFIC CONSTANTS AND SOCIO-DEMOGRAPHICS

The parameters for the alternative specific constants and the interaction variables for living environment as well as the variable for the number of cars per household with the alternatives are estimated by the models. Since for the short-term mode choice experiment there were four different commuting trip distance categories at which respondents had to make decisions for the choice situations, the aforementioned parameters were calculated for each of these four categories, as can be seen in table 6.13. The results of the models for the commuting trips for the trip distances of 7.5, 22.5, 45 and 75 kilometres are shown graphically in 6.2.

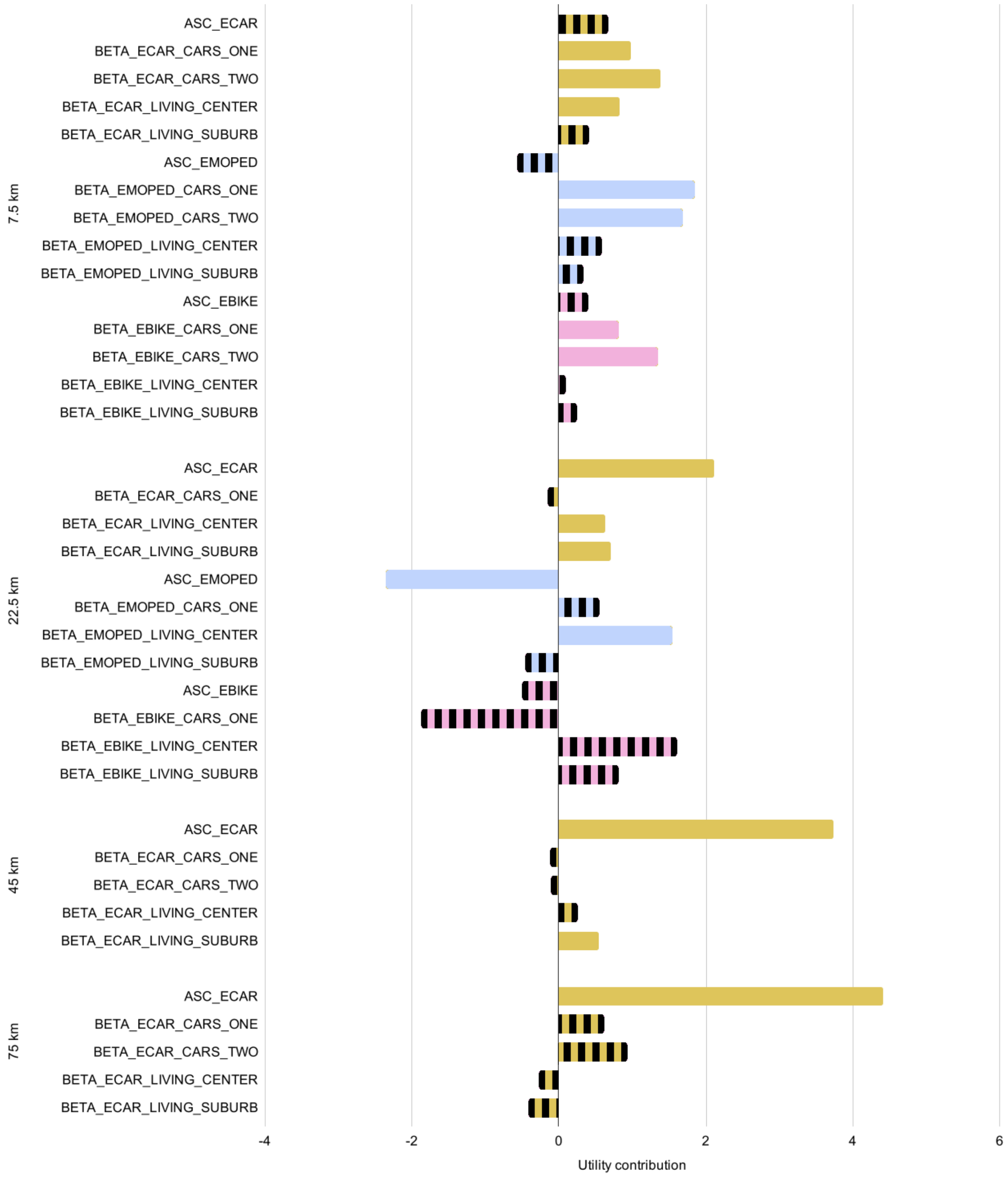


Figure 6.2: Utility contributions in the short-term mode choice experiment of the alternative specific constants, the number of cars per household and the living environment of the three shared mobility service alternatives for the four commuting trip distances for short-term mode choice experiment. Blocked bars indicate that the parameter is not statistically significant at the 95% confidence level. Yellow indicates the shared e-car, light blue the shared e-moped and pink the shared e-bike.

The models for 7.5 and 22.5 kilometres contains three alternative specific constants, and the models for 45 and 75 kilometres contains only one alternative specific constant. The ASCs indicate the respondent's preference for that alternative, which is not represented by the attributes included in the model. The value of the ASCs are relative utility contributions compared to the ASC of the private car alternative set to zero. The results of the models show that for commuting trips of 7.5 kilometres the use of the shared e-car is more preferred to the shared e-moped. Similarly, for a distance of 22.5 kilometres, the shared e-car is more preferred to the shared e-moped. For this distance, another remarkable insight is that the shared e-car is more preferred to the private car. The preference of the shared e-car over the private car for work-related trips is a remarkable preference, as the survey with the experiments was only completed by car owners. Nevertheless, the decision to opt for a mode depends on many factors, such as the cost and walking times associated with the modes. For commuting trip distances of 45 and 75 kilometres, again the use of the shared e-car is more preferred to the private car.

For commuting trips of 7.5 kilometres, the model results shows that people living in households with one or two cars have more preference for using a shared e-car, shared e-moped or shared e-bike than people living in households with three cars or more. Moreover, people living in households with two cars have more preference for using a shared e-car or shared e-bike for commuting trips of 7.5 kilometres than people living in households with one car. For the commuting trip distances of 22.5, 45 and 75 kilometres, no clear trend is found due to the lack of significance of the variables found and the insignificance of the differences between the variables.

The model shows that for work-related trips of 7.5 km, residents of city centres are more inclined to use shared e-cars for commuting purposes than residents in a rural area. Moreover, people living in a city centre are more inclined to use a shared e-car than people living in a suburban area and thus also in a rural area. For work-related trips of 22.5 kilometres, the model shows that residents of a city centre and a suburb are more likely to use a shared e-car than people from a more rural area. In addition, city centre residents are more inclined to use a shared e-moped than people living in a more rural area. For commuting trips of 45 and 75 kilometres, there is no clear trend in preference for the use of shared e-cars between residents of city centres, suburban areas and more rural areas.

ACCESS AND EGRESS TIME ATTRIBUTES

The parameters regarding both the access and egress time attributes for the private car, shared e-car, shared e-moped and the shared e-bike alternatives for the four different commuting distances are estimated by the models, as shown in table 6.13. The results of the models for the commuting trips for the trip distances of 7.5, 22.5, 45 and 75 kilometres are shown graphically in 6.3.

There seems to be no trend for the sensitivity of the access time and egress time attributes within the four alternatives. Therefore, it can be assumed that respondents did not perceive access time and egress time differently in the choice experiments. One possible cause could be that respondents only looked at the total trip time and not so much at the various components of which the total trip time consisted, see figure 5.2.

For the sensitivity of the walking times between the different alternatives there seems to be a trend, the trend is not very strong. The walking times refer to the access and egress walking times for the different alternatives. For both the commuting trip of 7.5 and 22.5 km, the sensitivity to walking times seems to be highest for the shared e-bike. Followed by the shared e-moped. The walking times of the the private car are almost equally sensitive to the walking times of the shared e-car. For commuting trips of 45 and 75 kilometres, there is no difference between the sensitivity of the walking time for the private car and the shared e-car. A change in walking time is assessed the same for the private car as for the shared e-car for commuting trips of 45 and 75 kilometres.

COST ATTRIBUTES

The parameters regarding the travel cost attributes for the private car, shared e-car, shared e-moped and the shared e-bike alternatives for the four different commuting distances are estimated by the models, as shown in table 6.13. The results of the models for the commuting trips for the trip distances of 7.5, 22.5, 45 and 75 kilometres are shown graphically in 6.4.

Figure 6.4 shows that for the work-related trips of 7.5 and 22.5 kilometres, the sensitivity to an increase in the travel cost for the shared e-car is the highest. This means that an increase in the price to be paid per kilometre for the shared e-car has more negative impact than the same increase in travel costs for the shared e-moped and the shared e-bike on the preference for these alternatives. For the work-related distances of 45 and 75 kilometres, there were only two alternatives, therefore for these two distances the only thing that can

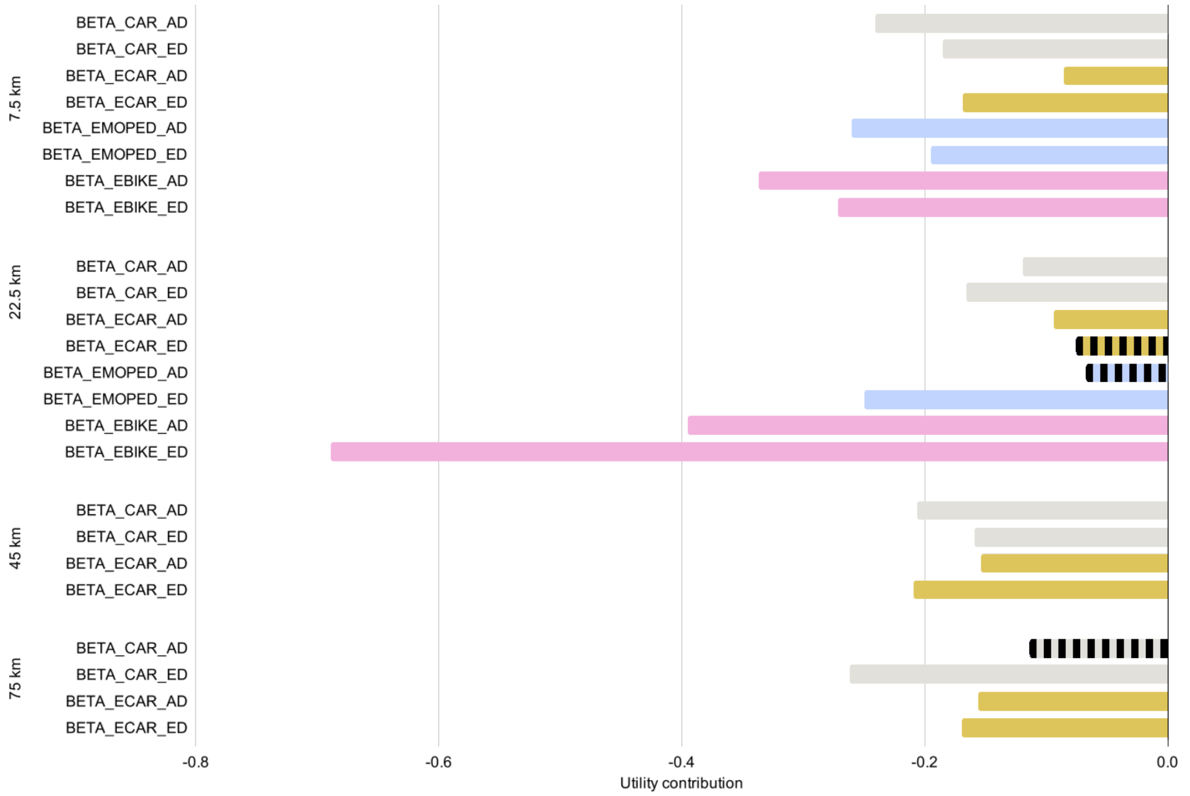


Figure 6.3: Utility contributions of the access and egress time attributes of the private car and the three shared mobility service alternatives for the four commuting trip distances for short-term mode choice experiment. Blocked bars indicate that the parameter is not statistically significant at the 95% confidence level. Light grey indicates the private car, yellow the shared e-car, light blue the shared e-moped and pink the shared e-bike.

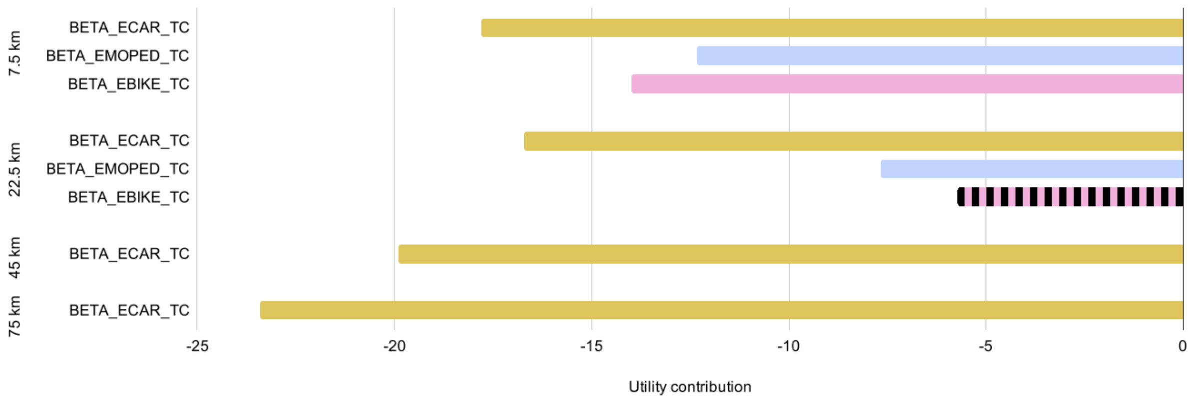


Figure 6.4: Utility contributions of the travel cost attributes of the three shared mobility service alternatives for the four commuting trip distances for short-term mode choice experiment. Blocked bars indicate that the parameter is not significant at the 95% confidence level. Yellow indicates the shared e-car, light blue the shared e-moped and pink the shared e-bike.

be concluded is that the sign of the parameter is correct. In other words, an increase in the travel cost for the shared e-car reduces the preference for that alternative.

6.3.2. LONG-TERM MODEL

In table 6.14, the estimated parameter values are listed for the long-term model. The table shows the significance levels of the parameters for the confidence levels of 99%, 95% and 90%. On these confidence levels, the parameters have the expected sign.

Table 6.14: Parameter estimations of extended MNL models for long-term mode choice experiment. *** indicates significant on a 99% confidence level, ** indicates significant on a 95% confidence level, * indicates significant on a 90% confidence level.

	500 km					1500 km					2500 km				
Name	**Value**	**Robust Std err**	**Robust t-test**	**p-value**		**Value**	**Robust Std err**	**Robust t-test**	**p-value**		**Value**	**Robust Std err**	**Robust t-test**	**p-value**	
Private car															
ASC_CAR	-1.15	0.378	-3.04	0	***	-2.9	0.502	-5.77	0	***	-3.26	0.657	-4.96	0	***
BETA_CAR_AD	-0.154	0.0247	-6.22	0	***	-0.198	0.0328	-6.06	0	***	-0.302	0.0437	-6.91	0	***
BETA_CAR_CARS_ONE	-1.22	0.242	-5.02	0	***	-0.248	0.272	-0.91	0.36		-0.684	0.355	-1.92	0.05	*
BETA_CAR_CARS_TWO	-1.08	0.231	-4.67	0	***	-0.359	0.25	-1.44	0.15		-0.944	0.309	-3.06	0	***
BETA_CAR_LIVING_CENTER	-0.363	0.152	-2.39	0.02	**	-0.561	0.196	-2.87	0	***	-0.123	0.271	-0.45	0.65	
BETA_CAR_LIVING_SUBURB	-0.072	0.133	-0.54	0.59		-0.369	0.154	-2.39	0.02	**	-0.361	0.202	-1.79	0.07	*
E-hub (Reference Alternative)															
BETA_EHUB_AD	-0.205	0.0256	-8	0	***	-0.284	0.0345	-8.21	0	***	-0.289	0.0459	-6.29	0	***
BETA_EHUB_SF	-0.0151	0.00369	-4.09	0	***	-0.0134	0.00473	-2.82	0	***	-0.0141	0.00659	-2.14	0.03	**
BETA_EHUB_SCENARIO_HI	-0.491	0.171	-2.87	0	***	-0.471	0.22	-2.14	0.03	**	-0.424	0.285	-1.49	0.14	
BETA_EHUB_SCENARIO_MED	-1.04	0.17	-6.15	0	***	-1.24	0.22	-5.66	0	***	-1.59	0.272	-5.84	0	***
BETA_EHUB_SCENARIO_LOW	-2.04	0.18	-11.35	0	***	-2.2	0.239	-9.19	0	***	-2.6	0.294	-8.87	0	***
BETA_EHUB_TC_ECAR	-2.99	0.643	-4.64	0	***	-7.34	0.88	-8.34	0	***	-11.7	1.2	-9.78	0	***
BETA_EHUB_TC_EMOPED	-0.744	0.479	-1.55	0.12		-2	0.642	-3.12	0	***	-2.36	0.929	-2.54	0.01	**
BETA_EHUB_TC_EBIKE	0.095	0.892	0.11	0.92		1.01	1.1	0.92	0.36		-1.13	1.49	-0.76	0.45	

ALTERNATIVE SPECIFIC CONSTANTS AND SOCIO-DEMOGRAPHICS

The parameters regarding the alternative specific constants and the interaction variables for living environment as well as the variable for the number of cars per household with the alternatives are estimated by the models. Since for the long-term mode choice experiment there were three different monthly distance categories at which respondents had to make decisions for the choice situations, the aforementioned parameters were calculated for each of these three categories, as can be seen in table 6.14. The results of the models for the monthly travel distances for 500 kilometres, 1500 kilometres and 2500 kilometres are shown graphically in figure 6.5.

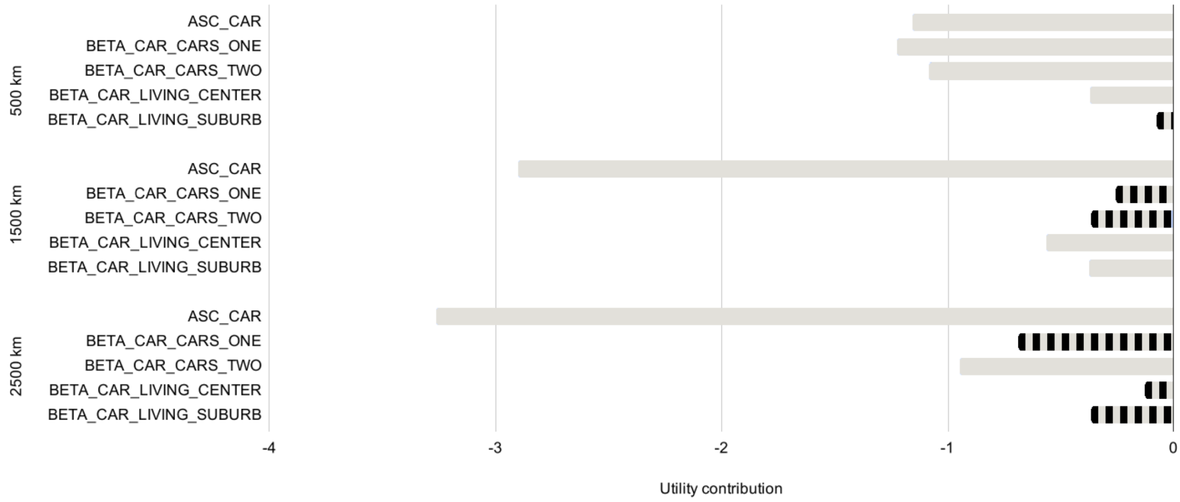


Figure 6.5: Utility contributions of the alternative specific constants, the number of cars per household and the living environment for long-term mode choice experiment. Blocked bars indicate that the parameter is not significant at the 95% confidence level.

Each model contains only one alternative specific constant, indicating the respondent's preference for that alternative, which is not represented by the attributes included in the model. The value of this ASC are relative utility contributions compared to the ASC of the e-hub alternative set to zero. Considering the values of the different ASCs for the private car alternative for the three monthly travel distances, it seems that for all three distances the mobility hub is preferred over the private car for these distances. This is a remarkable preference, as the survey with the experiments was only completed by car owners. Nevertheless, the decision of giving up the private car and using the mobility hub depends on many factors such as the costs and walking times associated with the mobility hub.

For a monthly distance of 500 kilometres, a negative utility contribution is found for respondents who live in a household with one or two cars compared to households that own three or more cars. This means that respondents who have a household with one or two cars are more likely to give up the least used car and use mobility hubs for trips than those who have three cars in the household.

Finally, for the monthly distances of 500 and 1500 kilometres there is a negative utility contribution for respondents living in a city centre compared to respondents living in a rural area. This implies that respondents living in a city centre are more inclined to give up the least used private car and make use of mobility hubs than respondents living in a more rural area.

ACCESS TIME ATTRIBUTES

The parameters regarding access time attributes for the private car and for the e-hub alternative for the three different monthly trip distances are estimated by the models, as shown in table 6.14. The result of the models for the monthly travel distances for the three monthly travel distances of 500, 1500 and 2500 kilometres are shown graphically in figure 6.6.

For both a monthly travel distance of 500 and 1500 kilometres, the sensitivity to an increase in walking time is greater for the mobility hub alternative than for the private car alternative, as can be seen in figure 6.6. This means that an increase in the walking time for the mobility hub alternative has a greater negative impact on the preference for that alternative than an equal increase in the walking time for the private car alternative.

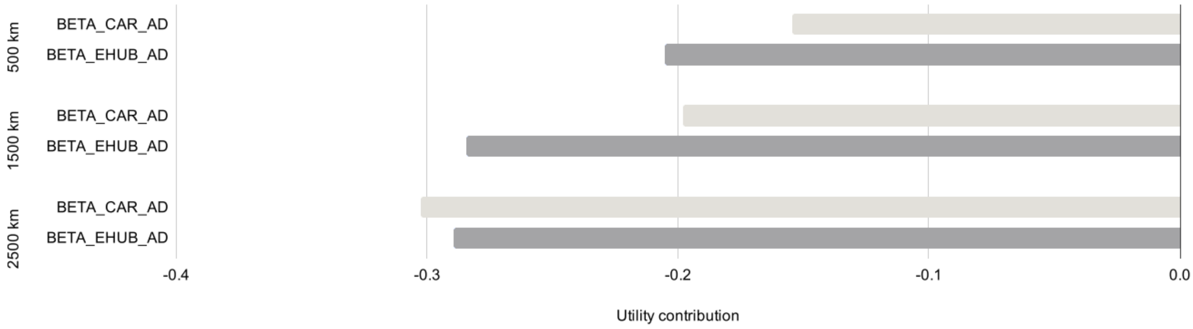


Figure 6.6: Utility contributions of the access time attributes of the private car and mobility hub alternatives for the three monthly travel distances for long-term mode choice experiment. Blocked bars indicate that the parameter is not significant at the 95% confidence level. Light grey indicates the private car, and dark grey the mobility hub.

COST ATTRIBUTES

The costs for the use of the mobility hub are, as described in chapter 5, divided into operating cost for the different shared mobility alternatives and subscription fee. The parameters were estimated by the models for the three different monthly travel distances, as shown in table 6.14. The results for the monthly distances of 500, 1500 and 2500 kilometres are shown graphically in figures 6.7 and 6.8.

The parameters regarding the operating cost attributes for shared e-car, e-moped and e-bike options within the mobility hub alternative for the three different monthly trip distances are estimated by the models, as shown in table 6.14. The results of the models for the monthly travel distances of 500, 1500 and 2500 kilometres are shown graphically in figure 6.7.

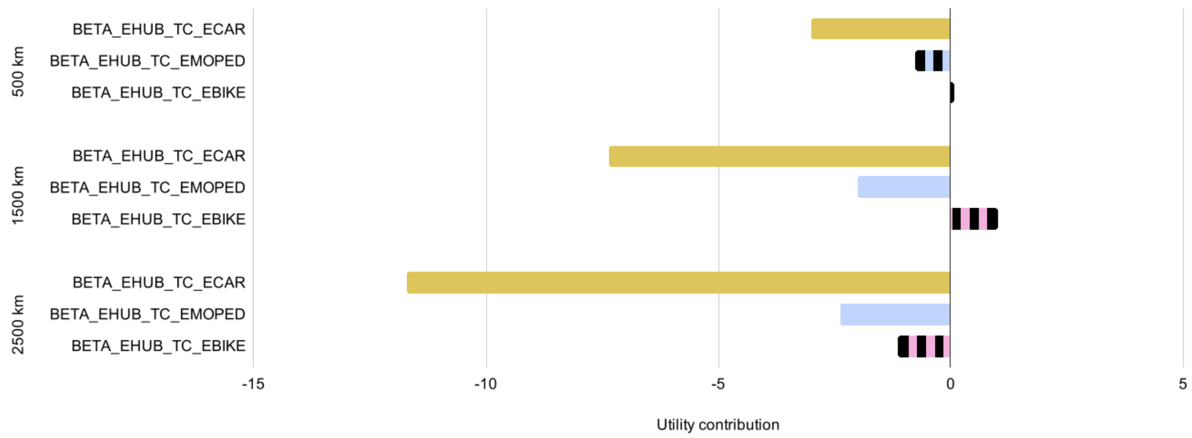


Figure 6.7: Utility contributions of the operating cost attributes of the different shared services options within the mobility hub alternative for the three monthly travel distances for long-term mode choice experiment. Blocked bars indicate that the parameter is not significant at the 95% confidence level. Yellow indicates the shared e-car, light blue the shared e-moped and pink the shared e-bike.

Figure 6.7 shows that for all three monthly travel distances, the sensitivity to an increase in operating costs for the shared e-car is the highest. This means that an increase in the price to be paid per kilometre for the shared e-car has more negative impact than the same increase in operating costs for the shared e-moped and e-bike on the preference for the mobility hub alternative. For the monthly distance of 1500 kilometres, the sensitivity for the operating costs of the shared e-moped is higher than the shared e-bike.

The parameters regarding the subscription fee attribute for the mobility hub alternative for the three different monthly travel distances are estimated by the models, as shown in table 6.14. The results of the models for the monthly travel distances of 500, 1500 and 2500 kilometres are shown graphically in figure 6.8

Figure 6.8, shows that the sensitivity to the subscription fee for the different monthly distances is almost identical. This indicates that for an increase in the subscription fee for the use of the mobility hub the effect on the preference for the mobility hub for the three monthly travel distances is more or less the same.

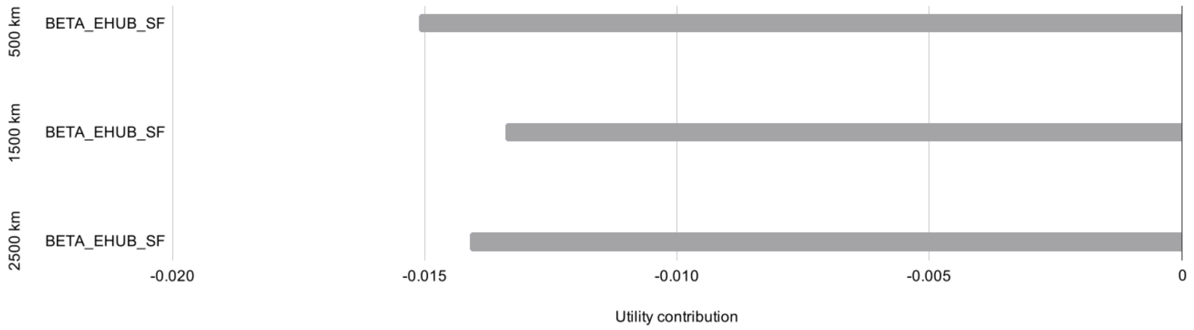


Figure 6.8: Utility contributions of the subscription fee attribute of the mobility hub alternatives for the three monthly travel distances for long-term mode choice experiment.

USAGE SCENARIO ATTRIBUTES

The parameters regarding the scenario attribute for the mobility hub alternative for the three different monthly trip distances are estimated by the models, as shown in table 6.14. The scenario attribute is added to the MNL model as a dummy variable consisting of three binary variables, as shown in equations 6.6 and 6.12. The results of the models for the monthly travel distances of 500, 1500 and 2500 kilometres are shown graphically in figure 6.9.

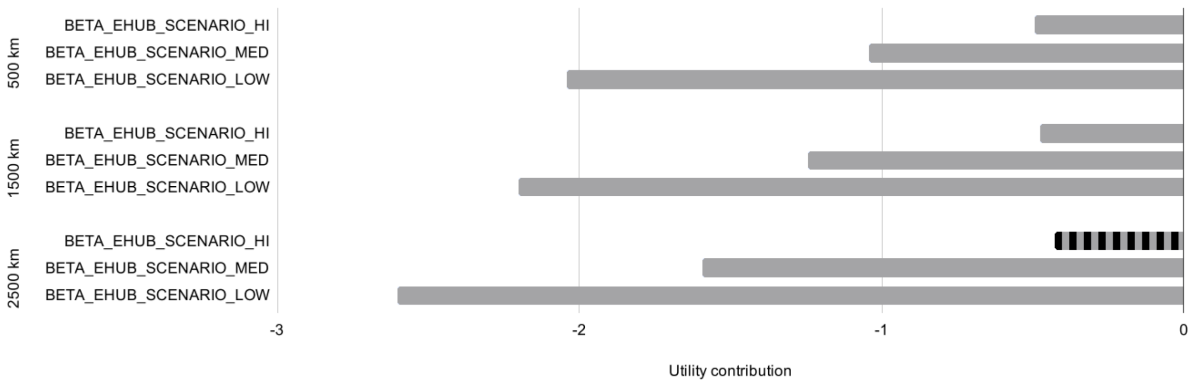


Figure 6.9: Utility contributions of the usage scenario attribute of the mobility hub alternative for the three monthly travel distances in the long-term mode choice experiment. Please refer to table 6.15 for the meaning of the different dummy variables. Blocked bars indicate that the parameter is not significant at the 95% confidence level.

Figure 6.9 shows graphically the utility contributions of the different scenario levels. The description of the different attribute categories can be found in table 6.15. The reference level is the scenario with full car use. The scenario levels with high, medium and low shared e-car use have a negative utility contribution compared to the reference level over all distances. This indicates that the respondents from this research prefer the full use of the shared e-car from the mobility hub as a substitute for the private car in the long term. The scenario with low shared e-car use has the highest negative utility contribution for all monthly distances. Followed by the scenario with medium shared e-car use for all distance, high shared e-car use gives even less negative utility contribution for all three monthly distances. Respondents prefer full use of the shared e-car and have little preference for the use of the shared e-moped and shared e-bike in combination with the shared e-car on a monthly basis.

Table 6.15: Attribute level explanation for the usage scenario attribute for long-term mode choice experiment. BETA_EHUB_SCENARIO_FULL is the reference dummy variable for the scenario attribute and is therefore not shown in figure 6.9

Attribute category	Description
BETA_EHUB_SCENARIO_FULL	100% of the trips with a shared e-car
BETA_EHUB_SCENARIO_HI	85% of the trips with a shared e-car, 10% with a shared e-moped, and 5% with a shared e-bike
BETA_EHUB_SCENARIO_MED	70% of the trips with a shared e-car, 20% with a shared e-moped, and 10% with a shared e-bike
BETA_EHUB_SCENARIO_LOW	55% of the trips with a shared e-car, 30% with a shared e-moped, and 15% with a shared e-bike

The utility contributions of full shared e-car use to low shared e-car use is not linear, as can be seen in figure 6.9. The negative utility contribution is the result of a combination in the growth of use of shared e-mopeds and shared e-bikes and a decrease in the use of the shared e-car. It is unclear whether the negative utility contribution is caused by a growth in the use of the shared e-moped or the shared e-bike or by a decrease in the shared e-car use. As discussed above and shown in appendix D.2.2, the use of the shared e-moped is rated best by the respondents, followed by the shared e-car and worst by the shared e-bike. Since the shared e-bike is rated worse than the shared e-moped, an increase in the use of the shared e-bike could possibly give an additional negative utility contribution. However, this cannot be clearly concluded from the results. The respondents show that despite the better rating of the shared e-moped over the shared e-car and e-bike, in the long run full shared e-car use is preferred over a combination of different shared alternatives with the shared e-car.

6.4. CONCLUSION

The sample of respondents for this research consists mainly of inhabitants of South Holland, North Holland and Utrecht. Sufficient respondents were found in the focus areas of this research, namely the city centres, suburbs and rural areas. The respondents were mainly young people who are highly educated and have a high income. Most respondents have used the shared bike and least the shared car. Respondents rated the shared moped best, followed by the shared car while the shared e-bike was rated worst.

Interesting insights are obtained for the effects of mobility hubs in the short term. The shared e-car is an interesting option instead of the private car for work-related trips. For the 22.5, 45 and 75 kilometres there is even more preference than the private car. For commuting trips of 7.5 kilometres, the model results shows that people living in households with one or two cars have more preference for using a shared e-car, shared e-moped or shared e-bike than people living in households with three cars or more. Moreover, people living in households with two cars have more preference for using a shared e-car or shared e-bike for commuting trips of 7.5 kilometres than people living in households with one car. Residents of city centres have more preference for the use of the shared e-car than residents of suburban and rural areas for commuting trips of 7.5 kilometres. For commuting trips of 22.5 kilometres, residents of city centres and suburban areas are more inclined to use the shared e-car than residents of rural areas. The trip costs for the commuting trip are important. The sensitivity of the trip costs for the shared e-car is higher than that of the shared e-moped and the shared e-bike, implying that for an equal increase in trip costs, the shared e-car generates higher disutilities than the shared e-moped and shared e-bike. There is no trend for the sensitivity of the access and egress time within a trip with an alternative. The times to be walked for the access trip and egress trip are assessed the same. However, there is a trend between the different alternatives. The sensitivity for the walking time of the shared e-bike seems to be the highest, followed by the shared e-moped. The walking times of the private car are almost equally sensitive to the walking times of the shared e-car for commuting trip distances of 7.5 and 22.5 kilometre. For the travel costs the sensitivity of the shared e-car is higher than the shared e-moped and shared e-bike.

For the long-term effects of mobility hubs, interesting insights are obtained. There seems to be a preference for mobility hubs over private cars. However, the willingness to give up the private car depends of course on many factors. For a monthly travel distance of 500 kilometres, people living in households with one or two cars are more likely to give up the least used car than people living in households with three cars or more. Furthermore, people who travel 500 or 1500 kilometres a month by private car and who live in a city centre are more likely to give up their private car and use mobility hubs than people who live in a rural area with the same monthly travel distance. The sensitivity to an increase in the walking time from home to the mobility hub is higher than to the private car for a monthly travel distance of 500 and 1500 kilometres. For all monthly travel distances, the sensitivity to an increase in travel costs is highest for the shared e-car, and consequently more than for the shared e-moped and shared e-bike. Car owners who give up the private car and start using mobility hubs prefer using the shared e-car from the mobility hub for trips the most. In the long run, car owners prefer full use of shared e-car, and have little preference for using the shared e-moped and shared e-bike.

7
EFFECTS OF MOBILITY HUBS IN RESIDENTIAL AREAS

The results of the models are used to analyse the influence of mobility hubs on car use and car ownership for three residential areas in the Randstad in the Netherlands. Section 7.1 elaborates on the analysis plan. Section 7.2 describes the focus areas. Following that, section 7.3 discusses the scenario design. Next, section 7.4 discusses the scenario results. Finally, section 7.5 elaborates on the conclusions.

7.1. ANALYSIS PLAN

For this research, it is relevant to assess the effects of mobility hubs in neighbourhoods, more than to gain insight on an individual level. Therefore, both the short term and long term models are used in this chapter to make an estimate of the car use and car ownership at neighbourhood level.

Three different types of locations are considered in this study. For these three locations, the influence of mobility hubs on car use and car ownership is assessed. There are several strategies from Dutch municipalities to reduce car use and car ownership by offering shared mobility services. The strategies considered in this research are based on the variables from the models for both the short and long term. The strategies concern the walking time to shared mobility services, and the price to be paid for their use.

7.2. FOCUS AREAS

Three types of areas are considered in this study. The first area is a city centre for a Dutch city in the Randstad. The second area is a suburb on the outskirts of a city. The last area is a rural area. It concerns existing neighbourhoods for all three locations. The locations were decided after discussions and meetings with consultants from Sweco. There is a demand for shared mobility and therefore mobility hubs from various large and small cities with different degrees of urbanisation. Furthermore, there is great interest from Sweco in the extent to which mobility hubs can influence car use and car ownership in these places. The city centre, suburban area and rural area in this study are based on three cities in the Netherlands, as described in appendix E.1.

The first focus area is a city centre. It concerns a typical city centre for a city in the Randstad. Despite the already low car ownership rate per household in city centres, there is a demand in the Netherlands for more car-free city centres [Gemeente Amsterdam, 2019, Utrecht, 2021]. In this study it is assumed that in a typical city centre for a city in the Randstad there are 0.50 cars per household, as explained in appendix E.1. Based on the discussions with consultants from Sweco, for a city centre a maximum walking time from home to a mobility hub of 5 minutes is appropriate and acceptable.

The second focus area is a suburban area. In this research, it is assumed that a suburban area borders on a city centre of a city in the Randstad region. In a suburban area there are half as many households per square kilometre but car ownership per household is twice as high compared to a city centre, see appendix E. In this research it is assumed that a suburban area in the Randstad there are 1.0 cars per household, as explained in appendix E.1. The same discussions with consultants of Sweco resulted in the assumption that for a suburban area a maximum time of 10 minutes to a mobility hub is suitable.

The final focus area is a rural area in a non-city area within the Randstad region. A rural area is an area with low urban density and high car ownership per household. This research assumes a rural area in the Randstad with 1.50 cars per household, as explained in E.1. For a more rural area, a maximum walking time of 10 minutes to a mobility hub appears to be suitable. In an area of low population density, it is not realistic to locate mobility hubs at a short maximum walking time from every house.

7.3. SCENARIO DESIGN

In order to obtain useful results concerning the impact of mobility hubs on car use and car ownership, it is important to have realistic scenarios for the three focus areas. First, it is essential to examine how different mobility hub grid plans relate to walking times from a household to a mobility hub. Secondly, it is necessary to have realistic values for the variables as input for both the short term and long term model. Finally, strategies from Dutch municipalities are needed that are specifically related to mobility hubs.

7.3.1. MOBILITY HUB GRID PLANS

In the Netherlands, as explained in section 2.3.2, different types and sizes of mobility hubs are realizable. Based on the discussions with consultants from Sweco, it became clear that there is interest from Dutch municipalities in the construction of different types of mobility hub grid plans. This research covers three types of mobility hub grid plans. The first type of grid plan consists of mobility hubs with a maximum walking time of 2 minutes from home to a mobility hub, which creates a high density hub grid plan. The second type of grid plan is formed by mobility hubs with a maximum walking time of 5 minutes, in this research this is called the intermediate density hub grid plan. Finally, a low density hub grid plan is composed of mobility hubs with a maximum walking time of 10 minutes in a built-up area. For the design of these grid plans, it is assumed that a walking time of 2,5 and 10 minutes equals 132,330 and 660 metres respectively.

HIGH DENSITY HUB GRID PLAN

The high density hub grid plan consists of a network of mobility hubs with a maximum walking time of 2 minutes from every household to a mobility hub. A high density mobility hub grid with a maximum walking time of 2 minutes is a very dense network of mobility hubs. This research shows that the average walking time to the private car is 2 minutes. Therefore, in this hypothetical scenario, the mobility hubs are located at the same walking time from home to the private car. A high density hub grid plan is an extreme situation, which is not likely to occur in the coming years. Nevertheless, the result of this study can provide insight into the potential benefits of creating a high density hub grid plan. Since the maximum walking time is 2 minutes, this mobility hub will mainly be realised in densely populated areas such as city centres and suburbs. In sparsely populated areas, this type of mobility hub will usually not be realised.

An estimate of how many mobility hubs have to be realised per square kilometre to cover all the homes in an area is shown graphically in figure 7.1. Please note, however, that it is assumed that the homes are evenly distributed over this area and that it is actually possible to build a perfect network of mobility hubs every 2 minutes. Figure 7.1, covers an area of 1320 metres by 1320 metres in which 50 mobility hubs are located, for a perfect distribution. This implies that 29 mobility hubs[1] per square kilometre must be realised.

In a balanced area with a perfectly distributed grid of mobility hubs, there are homes that are closer to the mobility hubs than the 2 minutes indicated. Assuming that all persons in the area have to walk 2 minutes to a mobility hub, could give an underestimation of the willingness of people to use shared mobility services. Therefore, it is important to estimate the percentage of people in this area who need to walk shorter times to a mobility hub. To get a more accurate estimate, the percentage of households living at a maximum walking time of 1 minute and 2 minutes from these mobility hubs is approximated here. A maximum walking time of 1 minute is represented by yellow circles in figure 7.2. The blue area is assumed to be at most 2 minutes' walking time to a mobility hub. This shows that in a perfectly distributed grid of small mobility hubs, about 39% live at a maximum of 1 minute walking time, and almost 61% live at a maximum of 2 minutes walking time. The exact values for the maximum walking times for perfect distribution can be found in table 7.1.

[1] 50 $hubs$ / 1.7424 km^2 = 28.696 $hubs/km^2$

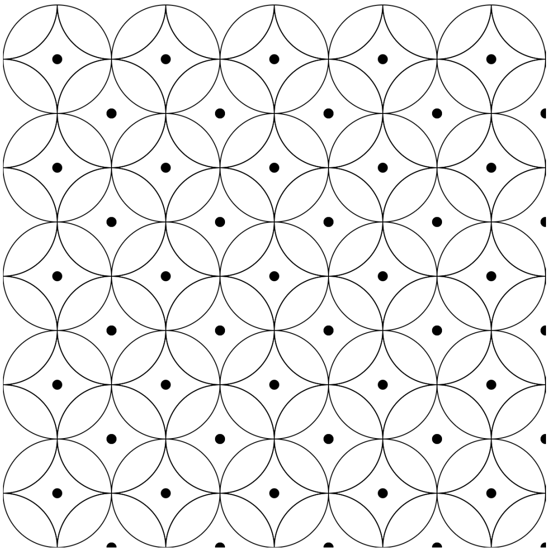


Figure 7.1: High density hub grid plan. The points represents a mobility hubs. The radius of the circle is 2 minutes representing the maximum walking time to that mobility hub.

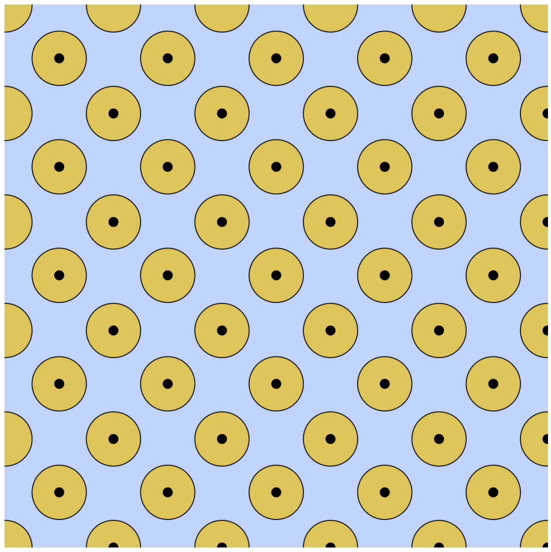


Figure 7.2: The same grid plan as in figure 7.1. However, here the different coloured areas represent a different maximum walking time to a mobility hub.

Table 7.1: Indication of the share of households at a walking time to a mobility hub for a high density hub grid plan.

Walking time	Percentage of total area
1 minute	39.3%
2 minutes	60.7%

INTERMEDIATE DENSITY HUB GRID PLAN

The intermediate density hub grid plan consists of a network of mobility hubs at a maximum walking time of 5 minutes from every household to a mobility hub. Since the maximum walking time is 5 minutes, this mobility hub will be mainly realised in densely populated areas such as city centres and suburbs. In sparsely populated areas, this type of mobility hub will usually not be realised.

An estimate of the number of mobility hubs that must be realised per square kilometre in order to cover all the homes in an area is shown graphically in figure 7.3. Figure 7.3, covers an area of 1320 metres by 1320 metres in which there are 8 mobility hubs, at a perfect distribution. This implies that about five mobility hubs[2] per square kilometre must be realised.

Similarly, in a balanced area with a perfectly distributed grid of mobility hubs, there are homes that are closer to the mobility hubs than the indicated 5 minutes. The area where people live at 1 minute from a mobility hub is shown in figure 7.4 by yellow circles. The blue area is assumed for people who live at a maximum of 2 minutes' walking time from a mobility hub. Next, the pink area represents the people living at 3 minutes' walking time from a mobility hub. Finally, the grey area represents people living at a maximum time of 5 minutes from a mobility hub. The exact values for the maximum walking times for perfect distribution can be found in table 7.2.

Table 7.2: Indication of the share of households at a walking time to a mobility hub for an intermediate density hub grid plan.

Walking time	Percentage of total area
1 minute	6.3%
2 minutes	18.9%
3 minutes	31.4%
5 minutes	43.5%

[2] $8\ hubs\ /\ 1.7424\ km^2 = 4.591\ hubs/km^2$

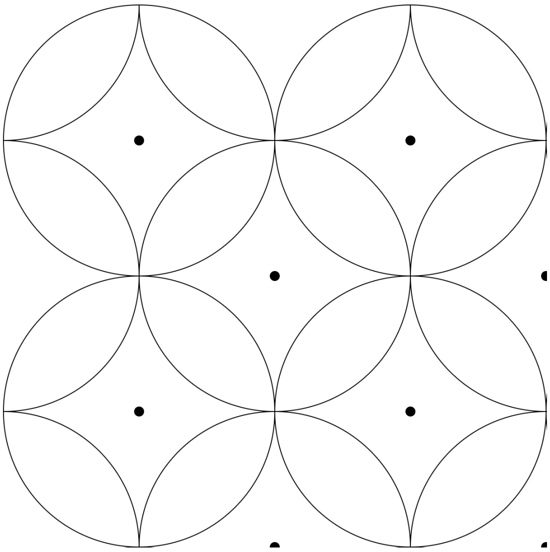


Figure 7.3: Intermediate density hub grid plan. The points represents a mobility hubs. The radius of the circle is 5 minutes representing the maximum walking time to that mobility hub.

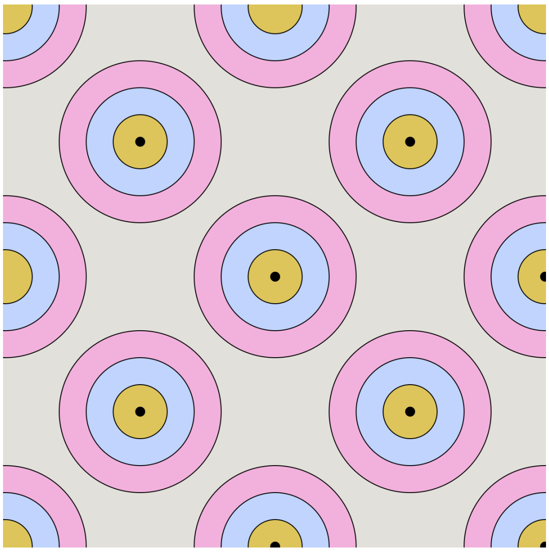


Figure 7.4: The same grid plan as in figure 7.3. However, here the different coloured areas represent a different maximum walking time to a mobility hub.

LOW DENSITY HUB GRID PLAN

Finally, the low density hub grid plan consists of a network of mobility hubs at a maximum walking time of 10 minutes from every household to a mobility hub. Given that the maximum walking time is 10 minutes, this mobility hub will mainly be located at the edge of an urban area, or in sparsely populated areas.

Figure 7.5 shows a graphical estimation of the number of mobility hubs that must be realised per square kilometre in order to cover all homes in an area. Figure 7.5, covers an area of 1320 metres by 1320 metres in which there are 2 mobility hubs, assuming a perfect distribution. This implies that approximately one mobility hub[3] must be realised per square kilometre.

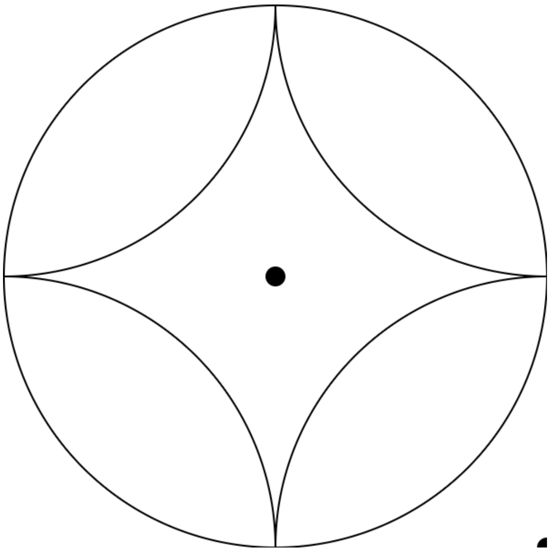


Figure 7.5: Low density hub grid plan. The points represents a mobility hubs. The radius of the circle is 10 minutes representing the maximum walking time to that mobility hub.

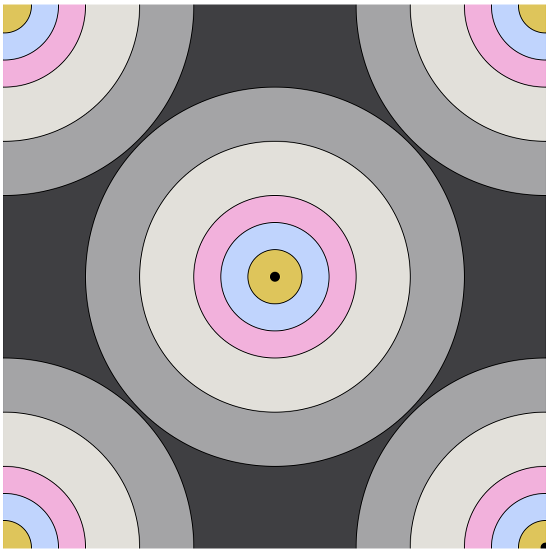


Figure 7.6: The same grid plan as in figure 7.5. However, here the different coloured areas represent a different maximum walking time to a mobility hub.

Similarly, in a balanced area with a perfectly distributed grid of mobility hubs, there are homes that are closer to the mobility hubs than the 10 minutes indicated. The area where people live at a maximum of 1 minute

[3] $2\ hubs\ /\ 1.7424\ km^2 = 1.148\ hubs/km^2$

from a mobility hub is shown in figure 7.6 by yellow circles. The blue area is assumed to represent people living at a maximum of 2 minutes walking time from a mobility hub. Next, the pink area represents the people living at 3 minutes' walking time from a mobility hub. The light grey area represents a maximum time of 5 minutes from home to mobility hub. A shade of darker grey reflects the area where people live at a maximum time of 7 minutes from the mobility hub. Finally, the dark grey area represents people living at a maximum time of 10 minutes from a mobility hub. The exact values for the maximum walking times for perfect distribution can be found in table 7.3.

Table 7.3: Indication of the share of households at a walking time to a mobility hub for a low density hub grid plan.

Walking time	Percentage of total area
1 minute	1.6%
2 minutes	4.7%
3 minutes	7.9%
5 minutes	25.1%
7 minutes	37.7%
10 minutes	23.0%

CONCLUSION ON THE MOBILITY HUB GRID PLANS

Due to the different maximum range there are large differences between the grid hub plans, as can be seen in table 7.4. When a strategy is to realise high density of mobility hubs in a city, many mobility hubs per square kilometre have to be built. However, the number of mobility hubs per square kilometre is already much less when the maximum walking time is 5 minutes. Only one mobility hub per square kilometre is needed when there is interest in building mobility hubs every 10 minutes.

Table 7.4: Number of mobility hubs per square kilometre for the hub grid plans. In brackets is the number of unrounded mobility hubs per square kilometre.

Mobility hub grid plan	Number of mobility hubs per square kilometre
High density hub grid plan	29 (28.696)
Intermediate density hub grid plan	5 (4.591)
Low density hub grid plan	1 (1.148)

Table 7.5, shows the percentage of people with a certain walking time to a mobility hub based on the grid plan of mobility hubs. It shows clearly that as the maximum walking time to a mobility hub increases, the relative percentage of people living close to a mobility hub decreases.

Table 7.5: Overview of the share of households at a maximum walking times to a mobility hub for the different hub grid plans.

	Percentage of total area		
Walking time	**High density**	**Intermediate density**	**Low density hub**
1 minute	39.3%	6.3%	1.6%
2 minutes	60.7%	18.8%	4.7%
3 minutes		31.4%	7.9%
5 minutes		43.5%	25.1%
7 minutes			37.7%
10 minutes			23.0%

7.3.2. INPUT VARIABLES

In order to estimate the effects of the mobility hubs and the strategies, it is important to use realistic values as input for the variables in the models. Realistic values should be used for the private car and shared mobility services. Furthermore, the traveler characteristics should be used in the right way in order to gain insight into the effects in the three focus areas.

PRIVATE CAR

For the private car, the access time and egress time must have realistic values as inputs to the models. These values are obtained from the results of the survey and discussions with experts.

In the survey, respondents were asked to indicate the walking time from home to private car in case the respondents did not have a parking space on their own property. As described in paragraph D.2.1, the average time from home to the private car is 2 minutes and 15 seconds. For simplicity, the access time from home to the private car is 2 minutes.

The egress time from a parking place to work depends very much on the location. From discussions with Sweco consultants, it appeared that it takes around 4 minutes on average. For that reason, 4 minutes is taken as input for the egress time in the short-term model.

SHARED MOBILITY SERVICES

For the shared mobility services, the access time and egress time must have realistic values as input for the models. Furthermore, the operating costs for the shared mobility services must be realistic. Finally, a decision is made on how car owners are expected to use the services from the hubs in the long term as input for the models. These values are obtained through results of the survey, literature and interviews with experts.

The input for the access time from home to the mobility hub depends on the mobility hub grid plan in the scenario. The percentages with the corresponding maximum walking times, as can be found in table 7.5, are used to give a more accurate estimate for the walking times of people in the focus areas. The percentages with the associated maximum walking times, in this case the access time, is used as input for the access time to a mobility hub that people have to walk for the mobility hub grid plans.

For simplicity, the same input values are used for the egress time for the short-term model as the input values for the access time. This means that the same mobility hub grid plan is assumed on the activity side as on the home side. It is therefore also assumed that, for the percentages shown in table 7.5, the percentages of people in a certain area have to walk less than the maximum walking time from a mobility hub to work for the three mobility hub grid plans.

In the Netherlands, there are several providers of shared mobility services. In order to obtain a realistic operating costs for the shared e-car, e-moped and e-bike, three providers in the Netherlands were considered, as explained in appendix E.2. Based on these providers, the operating costs per kilometre travelled for the three shared mobility alternatives can be found in table 7.6.

Table 7.6: The operating costs for the three shared mobility options in this research.

Alternative	**Operating costs**
Shared e-car	€ 0.268
Shared e-moped	€ 0.489
Shared e-bike	€ 0.123

The input for the subscription fee used in the long-term models is set at 30 euros per month. This is the result of the price that has to be paid per month for the use of the Hely Hubs, see appendix B.2. At the time of this research, Hely is the only operational mobility hub provider in the Netherlands. Therefore, the monthly price is based on Hely Hubs.

The long-term mode choice model shows that car owners have the greatest preference for full use of the shared e-car for trips, as can be read in section 6.3.2. Respondents show little preference for the use of the shared e-moped and the shared e-bike in the longer term, as a substitute for the private car. Therefore, as input for the long-term model, the preference for full use of the shared e-car was taken, which therefore assumes that people do not use the other shared mobility services from the mobility hub.

TRAVELER CHARACTERISTICS

The traveler characteristics should be used in the right way to gain insight in the effects in the three focus areas. In this way, the results of the models can provide insight into the effects for the different types of households in the different focus areas.

As discussed in the previous chapter, there is a dummy variable in the models for the living environment. Using this, both short-term and long-term effects of mobility hubs in these areas can be estimated. There are three focus areas in this research for which the effects of the mobility hubs are analysed. In the first focus area, a typical city centre area of a city in the Randstad, the city centre is used as the input value for the living environment dummy variable. In the second focus area, suburban area is the input value for the living environment dummy variable. The last focus area, is the rural area, here the model takes the rural area as input value for the living environment dummy variable.

The dummy variable for the number of cars per household is used in the model to estimate how car users will use the shared mobility services in the short term and the willingness to give up the least used private cars in a neighbourhood in the long term. Since the average number of cars per household for the three focus areas is known, the share of households with one car and the share of households with two cars can be derived. Based on the model, it is possible to determine how people in a one-car household in a certain neighbourhood with a certain hub grid plan will use the shared mobility services in the short term. In addition, with the same model it can be determined how people in a two-car household for the same grid plan will use the services. The share of one-car households in the neighbourhood should be multiplied by the outcome of the model. The same should be done with the share of two-car households and the outcome of the model for that plan. Next, the two modal splits are summed up. In this way a good estimate can be made of how people will use the shared mobility services in a defined living environment with a certain car ownership per household with a certain mobility hub plan. The longer-term effects are calculated in almost the same way. For the three focus areas, the share of households with one car and the share of households with two cars is known. This makes it possible to use the long-term model to determine for both types of households whether they will give up of the least used car and make use of the mobility hubs as a replacement for this car. The results of the model are multiplied by the corresponding shares of households with one or two cars. This gives a good indication of the extent to which people in the particular neighbourhoods are willing to give up their least used cars.

7.3.3. STRATEGIES

Municipalities in the Netherlands want to not only facilitate shared mobility services in cities, but also further stimulate the use of these services. There are several strategies in which the municipality could do this. In this research, only those strategies are analysed for which it is possible to assess the effects with the two models. The attributes of the mobility hub concern the walking time from home to the mobility hub, and the operating costs of the shared mobility services. Based on these attributes two strategies are found.

The municipality of Delft wants to offer more shared mobility services in the city in order to trigger a transition to less car use and car ownership. The city intends to do this by, among other things, offering more mobility hubs. By offering more mobility hubs, the maximum walking time to a hub is reduced for the households in the city. The second strategy is to reduce the operating costs of shared mobility services. The city of Amsterdam wants to lower the costs of using shared cars. Through these subsidies, the municipality of Amsterdam wants to reduce car use and car ownership.

CONSTRUCTION OF MORE MOBILITY HUBS

For the focus areas described above, different mobility hub grid plans are expected to be constructed in these areas. This became clear after the discussions with the consultants of Sweco, as discussed in section 7.2. An intermediate density hub grid plan was found to be suitable for a city centre. For both the suburban and rural area, a low density hub grid plan is appropriate. Increasing the number of mobility hubs causes the mobility hub grid plan to be more dense, and thus the walking times to a mobility hub to be shorter. The effect of a more dense hub grid plan compared to a less dense hub plan can be determined with the models. Therefore, for the three focus locations the short-term and long-term effects of two mobility hub grid plans are examined. Table 7.7 shows for the three focus areas which type of hub grid plans are analysed.

Table 7.7: The focus areas with the associated hub grid plans.

Focus area	Low density hub grid plan	Intermediate density hub grid plan	High density hub grid plan
City centre		•	•
Suburban area	•	•	
Rural area	•	•	

REDUCTION OF PRICES FOR SHARED MOBILITY SERVICES

The city of Amsterdam wants to lower the costs of shared cars in order to reduce car use and car ownership. This research includes a reduction of the travel costs of the shared e-bike and the shared e-bike as well. First, the short and long term effects of the original operating costs are examined for the focus areas with the two types of mobility hub grid plan. The original operating costs used as a basis in this research can be found in table 7.6. Then, for both scenarios, the effect is analysed if the original operating costs are reduced by 20% for the shared e-car, e-moped and e-bike. Finally, the additional effect when the original operating costs is reduced by 40% is again analysed for both scenarios. The operating costs per kilometre travelled for the shared mobility alternatives can be found in table 7.8.

Table 7.8: The operating costs for the three shared mobility options in this research.

Alternative	Original operating costs	20% reduction of original operating costs	40% reduction of original operating costs
Shared e-car	€ 0.268	€ 0.215	€ 0.161
Shared e-moped	€ 0.489	€ 0.392	€ 0.294
Shared e-bike	€ 0.123	€ 0.098	€ 0.074

7.4. SCENARIO RESULTS

The results of the scenarios for the city centre, suburban area and rural area are discussed in this section. Both short-term and long-term effects are considered. Moreover, for the three focus areas, the impact on the number of cars per household is examined on the basis of the scenarios.

7.4.1. CITY CENTRE

As explained in section 7.2, this research assumes that car ownership in a city centre of a city in the Randstad is estimated at 0.5 cars per household. For simplicity, it is assumed in this research that therefore 50% of households have one car. Hence, it is assumed that households cannot have two cars. For the city centre, there are two different mobility hub grid plans. Namely the high and intermediate density hub grid plans.

HIGH DENSITY HUB GRID PLAN

Short-term

The short term effects in a city centre with high density hub grid plan are shown in table 7.9. The distribution of the probabilities for the use of the private car and the three shared mobility alternatives are shown for the three pricing strategies.

Table 7.9: Probabilities of choosing the alternatives. Short-term effects for a city centre with a high density hub grid plan for different pricing strategies

Alternative	Original operating costs	20% reduction of original operating costs	40% reduction of original operating costs
Private car	63.8%	43.9%	24.5%
Shared e-car	21.2%	40.1%	59.9%
Shared e-moped	0.9%	1.7%	3.0%
Shared e-bike	14.2%	14.4%	12.6%

The use of the private car is the most attractive for commuting when the original operating costs are considered as input for the shared mobility alternatives. Moreover, the share of residents that would use a shared e-car for these trips is higher than that of the shared e-moped and e-bike together. The share of the shared e-moped and e-bike is small. Nevertheless, people have more preference for using the shared e-bike than for the shared e-moped.

The effects of reduced operating costs of the shared mobility alternatives show interesting trends for the use of shared mobility. The share of private car use decreases and the share of shared e-car use increases. The use of the shared e-car is even the most attractive if the original operating costs are reduced by 40%. The shares of the use of the shared e-moped and shared e-bike remain almost the same across the three proposed operating costs. For the three operating costs of the shared mobility services used in the models, people prefer the use of the shared e-bike to the use of the shared e-moped.

Long-term

The long-term effects in a city centre with a high density hub grid plan are shown in table 7.10. The distribution of the probabilities for the private car and the mobility hub are shown for the three pricing strategies. The probability of choosing the private car indicates whether the least used car will be kept. The probability of choosing the mobility hub indicates that the least used car will be given up and that the mobility hub will be used for these trips instead.

Table 7.10: Probabilities of choosing the alternatives. Long-term effects for a city centre with a high density hub grid plan for different pricing strategies.

Alternative	Original operating costs	20% reduction of original operating costs	40% reduction of original operating costs
Private car	39.0%	28.4%	19.1%
Mobility hub	61.0%	71.6%	80.9%

The long-term effects are large with respect to private car ownership. The willingness to give up the least used private car is large for a high density mobility hub grid plan. More than 60% of the households would give up the least used private car and use the mobility hubs to replace the private car. The attractiveness of the mobility hubs further increases as the operating costs of the shared mobility services decrease. As a result, more households will give up their least car and start using the shared mobility services offered in the mobility hubs.

INTERMEDIATE DENSITY HUB GRID PLAN

Short-term

The short term effects in a city centre with intermediate density hub grid plan are shown in table 7.11. The distribution of the probabilities for the use of the private car and the three shared mobility alternatives are shown for the three pricing strategies.

Table 7.11: Probabilities of choosing the alternatives. Short-term effects for a city centre with an intermediate density hub grid plan for different pricing strategies.

Alternative	Original operating costs	20% reduction of original operating costs	40% reduction of original operating costs
Private car	77.4%	59.8%	38.0%
Shared e-car	15.2%	31.5%	53.0%
Shared e-moped	0.6%	1.1%	2.1%
Shared e-bike	6.9%	7.5%	6.9%

The effects on the short term in a city centre with the original travel costs are shown in table 7.11. It is clear that the use of the private car is most attractive for commuting when the original operating costs for shared mobility services are considered as an input for the shared mobility alternatives. Moreover, the share of residents that would use a shared e-car for these trips is higher than that of the shared e-moped and e-bike together. The share of the shared e-moped and e-bike is small. Nevertheless, people have more preference for using the shared e-bike than for the shared e-moped.

The effects of reduced operating costs of the shared mobility alternatives show interesting trends for the use of shared mobility. The share for the use of the private car decreases and the share for the use of the shared e-car increases. The use of the shared e-car is even most attractive when the original operating costs are reduced by 40%. The shares of the use of the shared e-moped and shared e-bike remain almost the same across the three proposed operating costs. People prefer the use of the shared e-bike over the use of the shared e-moped for the three operating costs used in the models.

Long-term

The long-term effects in a city centre with a intermediate density hub grid plan are shown in table 7.12. The distribution of the probabilities for the private car and the mobility hub are shown for the three pricing strategies. The probability of choosing the private car indicates whether the least used car will be kept. The probability of choosing the mobility hub indicates that the least used car will be given up and that the mobility hub will be used for these trips instead.

The long-term effects for the three pricing strategies are shown in table 7.12. The effect of the advent of mobility hubs with an intermediate density hub grid plan is large. In this scenario, 50% of households would

Table 7.12: Long-term effects for a city centre with an intermediate density hub grid plan for different pricing strategies.

Alternative	Original operating costs	20% reduction of original operating costs	40% reduction of original operating costs
Private car	49.7%	39.0%	28.2%
Mobility hub	50.3%	61.0%	71.8%

give up the least used car. It is clear to see that with a reduction in travel costs for the three shared mobility alternatives that the attractiveness of the mobility hub increases. As a result, more households will give up their least car and start using the shared mobility services from the mobility hub.

The long-term effects are large with respect to private car ownership. The willingness to give up the least used private car is large for a intermediate density mobility hub grid plan. More than 50% of the households would give up the least used private car and use the mobility hubs to replace the private car. The attractiveness of the mobility hubs further increases as the operating costs of the shared mobility services decrease. As a result, more households will give up their least car and start using the shared mobility services of the mobility hubs.

EFFECTS OF CARS PER HOUSEHOLD IN A CITY CENTRE

The effects on the number of cars per household for the city centre scenarios are shown in table 7.13. The table shows the impact of the scenarios with the three pricing strategies on car ownership in a city centre.

Table 7.13: Effects of the scenarios with the different pricing strategies on the number of cars per household in the city centre of a typical city in the Randstad.

Mobility hub grid plan	Current situation	Original operating costs	20% reduction of original operating costs	40% reduction of original operating costs
High density	0.50	0.20	0.14	0.10
Intermediate density	0.50	0.25	0.19	0.14

As discussed in section 7.2, this research assumes that a typical city centre for a city in the Randstad has a car ownership rate of 0.50 cars per household. The effects on car ownership at neighbourhood level for the two mobility hub grid plans with three pricing strategies can be seen in table 7.13. The effect on giving up the least used private car is, with equal operating costs, greater with a grid plan having a higher mobility hub density than a grid plan having a lower mobility hub density.

7.4.2. SUBURBAN AREA

As explained in section 7.2, this research assumes that car ownership in a suburban area in the Randstad is estimated at 1.0 cars per household. For simplicity, it is assumed in this research that therefore 100% of households have one car. Hence, it is assumed that households cannot have 2 cars. For the suburban area, there are two different mobility hub grid plans. Namely the intermediate and the low density hub grid plans.

INTERMEDIATE DENSITY HUB GRID

Short-term

The short-term effects in a suburban area with intermediate density hub grid plan are shown in figure 7.14. The distribution of the probabilities for the use of the private car and the three shared mobility alternatives are shown for the three pricing strategies.

Table 7.14: Probabilities of choosing the alternatives. Short-term effects for a suburban area with an intermediate density hub grid plan for different pricing strategies.

Alternative	Original operating costs	20% reduction of original operating costs	40% reduction of original operating costs
Private car	76.9%	59.4%	38.0%
Shared e-car	15.3%	31.4%	52.2%
Shared e-moped	0.2%	0.6%	1.3%
Shared e-bike	7.6%	8.6%	8.6%

The effects on the short term with the original travel costs are shown in table 7.14. The use of the private car is the most attractive for commuting trips if the original travel costs are considered as input for the shared mobility alternatives. Moreover, the share of residents that would use a shared e-car for these trips is higher than that of the shared e-moped and e-bike together. The share of the shared e-moped and e-bike is small. Nevertheless, people have more preference for using the shared e-bike than for the shared e-moped.

The effects of reduced operating costs of the shared mobility alternatives show interesting trends for the use of shared mobility. The share for the use of the private car decreases and the share for the use of the shared e-car increases. The use of the shared e-car is even most attractive when the original operating costs are reduced by 40%. The shares of the use of the shared e-moped and shared e-bike remain almost the same across the three proposed operating costs. For each of the three operating costs of the shared mobility services used in the models, people prefer the use of the shared e-bike to the use of the shared moped.

Long-term

The long-term effects in a suburban area with a intermediate density hub grid plan are shown in table 7.15. The distribution of the probabilities for the private car and the mobility hub are shown for the three pricing strategies. The probability of choosing the private car indicates whether the least used car will be kept. The probability of choosing the mobility hub indicates that the least used car will be given up and that the mobility hub will be used for these trips instead.

Table 7.15: Long-term effects for a suburban area with an intermediate density hub grid plan for different pricing strategies.

Alternative	Original operating costs	20% reduction of original operating costs	40% reduction of original operating costs
Private car	53.1%	41.9%	30.8%
Mobility hub	46.9%	58.1%	69.2%

The long-term effects are large with respect to private car ownership. The willingness to give up the least used private car is large for a intermediate density mobility hub grid plan. Nearly 47% of the households would give up the least used private car and use the mobility hubs to replace the private car. The attractiveness of the mobility hubs further increases as the operating costs of the shared mobility services decrease. As a result, more households will give up their least car and start using the shared mobility services offered in the mobility hubs.

LOW DENSITY HUB GRID

Short-term

The short-term effects in a suburban area with a low density hub grid plan are shown in table 7.16. The distribution of the probabilities for the use of the private car and the three shared mobility alternatives are shown for the three pricing strategies.

Table 7.16: Probabilities of choosing the alternatives. Short-term effects for a suburban area with a low density hub grid plan for different pricing strategies.

Alternative	Original operating costs	20% reduction of original operating costs	40% reduction of original operating costs
Private car	88.3%	76.9%	58.5%
Shared e-car	8.8%	19.6%	37.3%
Shared e-moped	0.1%	0.3%	0.7%
Shared e-bike	2.8%	3.3%	3.5%

The use of the private car is the most attractive for commuting when the original travel costs are considered as input for the shared mobility alternatives. Moreover, the share of residents that would use a shared e-car for these trips is higher than that of the shared e-moped and e-bike together. The share of the shared e-moped and e-bike is small. Nevertheless, people have more preference for using the shared e-bike than for the shared e-moped.

The effects of reduced operating costs of the shared mobility alternatives show interesting trends for the use of shared mobility. The share for the use of the private car decreases and the share for the use of the shared e-car increases. The use of the private car remains the most attractive over all operating costs for shared mobility services used in the models. The shares of the use of the shared e-moped and shared e-bike remain almost the same across the three proposed operating costs. For each of the three operating costs of the shared mobility services used in the models, people prefer the use of the shared e-bike to the use of the shared moped.

Long-term

The long-term effects in a suburban area with a low density hub grid plan are shown in table 7.17. The distribution of the probabilities for the private car and the mobility hub are shown for the three pricing strategies. The probability of choosing the private car indicates whether the least used car will be kept. The probability of choosing the mobility hub indicates that the least used car will be given up and that the mobility hub will be used for these trips instead.

Table 7.17: Long-term effects for a suburban area with a low density hub grid plan for different pricing strategies.

Alternative	Original operating costs	20% reduction of original operating costs	40% reduction of original operating costs
Private car	67.9%	58.8%	48.0%
Mobility hub	32.1%	41.2%	52.0%

The long-term effects are significant with regard to private car ownership. The willingness to give up the least used private car is significant for a low density mobility hub grid plan. More than 32% of the households would give up the least used private car and use the mobility hubs to replace the private car. The attractiveness of the mobility hubs further increases as the operating costs of the shared mobility services decrease. As a result, more households will give up their least car and start using the shared mobility services offered in the mobility hubs.

EFFECTS OF CARS PER HOUSEHOLD IN A SUBURBAN AREA

The effects on the number of cars per household for the suburban area scenarios are shown in table 7.18. The table shows the impact of the scenarios with the three pricing strategies on car ownership in a suburban area.

Table 7.18: Effects of the scenarios with the different pricing strategies on the number of cars per household in a suburban area in the Randstad.

Mobility hub grid plan	Current situation	Original operating costs	20% reduction of original operating costs	40% reduction of original operating costs
Intermediate density	1.0	0.53	0.42	0.31
Low density	1.0	0.68	0.59	0.48

As discussed in section 7.2, this research assumes that a suburban area near a city in the Randstad has a car ownership rate of 1.0 cars per household. The effects on car ownership at neighbourhood level for the two mobility hub grid plans with three pricing strategies can be seen in table 7.18. The effect on giving up the least used private car is, with equal operating costs, greater with a grid plan having a higher mobility hub density than a grid plan having a lower mobility hub density.

7.4.3. RURAL AREA

As explained in section 7.2, this research assumes that car ownership in a rural area in the Randstad is estimated at 1.5 cars per household. For the sake of simplicity, this research assumes that 50% of households have one car and 50% have two cars per household. For the rural area, there are two different mobility hub grid plans. Namely the intermediate and the low density hub grid plans.

INTERMEDIATE DENSITY HUB GRID

Short-term

The short-term effects in a rural area with intermediate density hub grid plan are shown in table 7.19. The distribution of the probabilities for the use of the private car and the three shared mobility alternatives are shown for the three pricing strategies.

The use of the private car is the most attractive for commuting trips if the original operating costs are considered as input for the shared mobility alternatives. Moreover, the share of residents that would use a shared e-car for these trips is higher than that of the shared e-moped and e-bike together. The share of the shared

Table 7.19: Probabilities of choosing the alternatives. Short-term effects for a rural area with an intermediate density hub grid plan for different pricing strategies.

Alternative	Original operating costs	20% reduction of original operating costs	40% reduction of original operating costs
Private car	78.8%	63.3%	43.7%
Shared e-car	13.0%	27.0%	45.8%
Shared e-moped	0.2%	0.4%	1.0%
Shared e-bike	8.1%	9.2%	9.4%

e-moped and e-bike is small. Nevertheless, people have more preference for using the shared e-bike than for the shared e-moped.

The impact of reduced operating costs of the shared mobility alternatives reveals interesting results for the use of shared mobility. The share of private car use decreases and the share of shared e-car use increases. The use of the shared e-car is slightly more attractive if the original operating costs are reduced by 40%. The shares of the use of the shared e-moped and shared e-bike remain almost the same across the three proposed operating costs. People prefer to use of the shared e-bike over the shared e-moped for the three operating costs used in the models.

Long-term

The long-term effects in a rural area with a intermediate density hub grid plan are shown in table 7.20. The distribution of the probabilities for the private car and the mobility hub are shown for the three pricing strategies. The probability of choosing the private car indicates whether the least used car will be kept. The probability of choosing the mobility hub indicates that the least used car will be given up and that the mobility hub will be used for these trips instead.

Table 7.20: Long-term effects for a rural area with an intermediate density hub grid plan for different pricing strategies.

Alternative	Original operating costs	20% reduction of original operating costs	40% reduction of original operating costs
Private car	57.9%	47.1%	35.5%
Mobility hub	42.1%	52.9%	64.5%

The long-term effects are large with respect to private car ownership. The willingness to give up the least used private car is large for a intermediate density mobility hub grid plan. More than 42% of the households would give up the least used private car and use the mobility hubs to replace the private car. The attractiveness of the mobility hubs further increases as the operating costs of the shared mobility services decrease. As a result, more households will give up their least car and start using the shared mobility services offered in the mobility hubs.

LOW DENSITY HUB GRID

Short-term

The short-term effects in a rural area with a low density hub grid plan are shown in table 7.21. The distribution of the probabilities for the use of the private car and the three shared mobility alternatives are shown for the three pricing strategies.

Table 7.21: Probabilities of choosing the alternatives. Short-term effects for a rural area with a low density hub grid plan for different pricing strategies.

Alternative	Original operating costs	20% reduction of original operating costs	40% reduction of original operating costs
Private car	89.7%	79.6%	63.3%
Shared e-car	7.3%	16.7%	32.4%
Shared e-moped	0.1%	0.2%	0.5%
Shared e-bike	3.0%	3.5%	3.8%

The use of the private car is the most attractive for commuting when the original travel costs are considered as input for the shared mobility alternatives. Moreover, the share of residents that would use a shared e-car for these trips is higher than that of the shared e-moped and e-bike together. The share of the shared e-moped and e-bike is small. Nevertheless, people have more preference for using the shared e-bike than for the shared e-moped.

The impact of reduced operating costs of the shared mobility alternatives shows interesting results for the use of shared mobility. The share for the use of the private car decreases and the share for the use of the shared e-car increases. The use of the private car remains the most attractive across all operating costs used for shared mobility services in the models. The shares of the use of the shared e-moped and shared e-bike remain almost the same across the three proposed operating costs. People prefer to use the shared e-bike over the shared moped for the three operating costs used in the models.

Long-term

The long-term effects in a rural area with a intermediate density hub grid plan are shown in table 7.22. The distribution of the probabilities for the private car and the mobility hub are shown for the three pricing strategies. The probability of choosing the private car indicates whether the least used car will be kept. The probability of choosing the mobility hub indicates that the least used car will be given up and that the mobility hub will be used for these trips instead.

Table 7.22: Long-term effects for a rural area with a low density hub grid plan for different pricing strategies.

Alternative	Original operating costs	20% reduction of original operating costs	40% reduction of original operating costs
Private car	71.6%	63.3%	52.9%
Mobility hub	28.4%	36.7%	47.1%

The long-term effects are significant with regard to private car ownership. The willingness to give up the least used private car is significant for a low density mobility hub grid plan. More than 28% of the households would give up the least used private car and use the mobility hubs to replace the private car. The attractiveness of the mobility hubs further increases as the operating costs of the shared mobility services decrease. As a result, more households will give up their least car and start using the shared mobility services offered in the mobility hubs.

EFFECTS OF CARS PER HOUSEHOLD IN A RURAL AREA

The effects on the number of cars per household for the rural area scenarios are shown in figure 7.23. The figure shows the impact of the scenarios with the three pricing strategies on car ownership in a rural area.

Table 7.23: Effect of scenarios with different pricing strategies on the number of cars per household in a rural area in the Randstad.

Mobility hub grid plan	Current situation	Original operating costs	20% reduction of original operating costs	40% reduction of original operating costs
Intermediate density	1.50	1.08	0.97	0.86
Low density	1.50	1.22	1.13	1.03

As discussed in section 7.2, this research assumes that a rural area in the Randstad has a car ownership rate of 1.50 cars per household. The effects on car ownership at neighbourhood level for the two mobility hub grid plans with three pricing strategies can be seen in table 7.23. The effect on giving up the least used private car is, with equal operating costs, greater with a grid plan having a higher mobility hub density than a grid plan having a lower mobility hub density.

7.5. SCENARIO CONCLUSIONS

This chapter showed that mobility hub grid plans in the different areas and the travel costs for the shared mobility alternatives affect car use and car ownership. This section firstly presents conclusions for the short term, followed by conclusions for the long term and finally general conclusions.

7.5.1. SHORT-TERM CONCLUSIONS

The results for the three focus areas with the different mobility hub grid plans and the pricing strategies show that there is an effect on the use of the least used private car in the short term. The effect of mobility hubs on the reduced use of the least used private car is shown in table 7.24. The willingness to use shared mobility services is slightly higher in the city centre and suburban area than in the rural area, see tables E.6, E.7 and E.8. Therefore, the reduction in private car use in the city centre and suburban area is slightly greater than in the rural area. Moreover, a higher mobility hub density and a reduction of the operating costs of the shared mobility services lead to a greater reduction in the least used private car use.

Table 7.24: Overview of the reduction of the least used private car use for the different focus areas for the different strategies.

Focus area	Mobility hub grid plan	Original operating costs	20% reduction of original operating costs	40% reduction of original operating costs
City centre	High density	36.2%	56.1%	75.5%
	Intermediate density	22.6%	40.2%	62.0%
Suburban area	Intermediate density	23.1%	40.6%	62.0%
	Low density	11.7%	23.1%	41.5%
Rural area	Intermediate density	21.2%	36.7%	56.3%
	Low density	10.3%	20.4%	36.7%

The preference of car users for the use of the shared e-car as a substitute for the private car is high, see tables E.6, E.7 and E.8. Since the shared e-car most strongly resembles the private car in its characteristics and appearance, this is not a remarkable result. Following the shared e-car, the use of the shared e-bike is the second most popular alternative of the three shared mobility services. The preference for the use of the shared e-bike is greater as urban density decreases, see table E.7. There is hardly any preference for the use of the shared e-moped in the short term. Since the sample of respondents consists of car owners it can be explained that this group prefers to use an alternative that resembles the private car rather than a shared e-moped or e-bike which is a more active mode.

The reduction of the operating costs of the three shared mobility alternatives mainly leads to an increase in the preference for the shared e-car and a decrease in the preference for the least used private car, see tables E.6, E.7 and E.8. The share of the shared e-bike and e-moped remains almost the same across the different operating costs of the shared mobility alternatives. The preference for the use of the shared e-moped and the shared e-bike can be increased by lowering the travel costs of these alternatives or by increasing the operating cost of the shared e-car, as described in section 6.3.1 and 6.3.2.

Mobility hubs do not primarily reduce the number of car movements as can be seen in table 7.25. The table shows the share of the least used private car and the shared e-car together for commuting trips. The share of car movements is less as the density of the mobility hubs increases. In that case, car owners are more willing to opt for a shared e-moped or a shared e-bike.

Table 7.25: Overview of the share of trips using the least used private car and shared e-car for the different focus areas for the different strategies.

Focus area	Mobility hub grid plan	Original operating costs	20% reduction of original operating costs	40% reduction of operating travel costs
City centre	High density	85.0%	83.9%	84.4%
	Intermediate density	92.5%	91.4%	90.9%
Suburban area	Intermediate density	92.2%	90.8%	90.1%
	Low density	97.1%	96.4%	95.9%
Rural area	Intermediate density	91.7%	90.3%	89.5%
	Low density	97.0%	96.3%	95.7%

7.5.2. LONG-TERM CONCLUSIONS

The result for the three focus areas with the different mobility hub grid plans and the pricing strategies shows that there is an effect on car ownership in the long term at household level. The effect of mobility hubs on giving up the least used private car is shown in table 7.26. For the same mobility hub grid plan and the same operating costs, the willingness to give up the least used car is greatest for residents of the city centre, followed by those in the suburban area and least in the rural area. Moreover, a higher mobility hub density and a reduction in the operating costs of the shared mobility services lead to a greater reduction in car ownership in the focus areas.

Table 7.26: Overview of the share of households that would give up the least used private car for the different focus areas for the different strategies.

Focus area	Mobility hub grid plan	Original operating costs	20% reduction of original operating costs	40% reduction of original operating costs
City centre	High density	61.0%	71.6%	80.9%
	Intermediate density	50.3%	61.0%	71.8%
Suburban area	Intermediate density	46.9%	58.1%	69.2%
	Low density	32.1%	41.2%	52.0%
Rural area	Intermediate density	42.1%	52.9%	64.5%
	Low density	28.4%	36.7%	47.1%

The results on the willingness to give up the least used private car were used to determine the effect on car ownership at neighbourhood level. At neighbourhood level, the effects on car ownership for the three focus areas are shown in table 7.27. The process of obtaining these results is explained in detail in appendix E.3.2. The effect on the number of cars per household in the neighbourhood with the same mobility hub grid plan and the same operating costs is the largest in the city centre, followed by the suburban area and the smallest in the rural area. Despite the fact that in a city centre the smallest number of cars per household is found, the percentage decrease is still the strongest.

Table 7.27: Overview of the effect on the reduction of car ownership at neighbourhood level for the different focus areas for the different strategies.

Focus area	Mobility hub grid plan	Original operating costs	20% reduction of original operating costs	40% reduction of original operating costs
City centre	High density	61.0%	71.7%	80.9%
	Intermediate density	50.3%	61.0%	71.8%
Suburban area	Intermediate density	46.9%	58.1%	69.2%
	Low density	32.1%	41.2%	52.0%
Rural area	Intermediate density	28.1%	35.3%	43.0%
	Low density	18.9%	24.5%	31.4%

7.5.3. GENERAL CONCLUSIONS

Residents of the three focus areas are willing to use shared mobility services in both the short and long term under defined conditions. The willingness to use shared mobility services for commuting trips is slightly higher in the city centre and suburban area than in the rural area but not substantially different. While, the willingness to give up the least used car is clearly higher in the city centre than in the suburban area and even higher than in a rural area. Therefore, residents of a city centre are more willing to give up the least private car and use shared mobility services for all travel motives than residents of a suburban area and rural area.

For the focus areas with the same mobility hub grid plan and the same operating costs, the models show that the willingness to give up the least used car in the long term is greater than the willingness to use a shared mobility alternative for commuting trips. This might be caused by the design of the stated choice experiments and the associated information. In the stated choice experiments, there was full insight into the trip costs and the total costs per month for both the private car and the shared mobility services. This gave the respondents clear insight into the costs they could save per trip and per month by giving up the least used car and start using shared mobility services. The amount that can be saved each month is greater than the amount for one trip. The financial decision to give up the private car may therefore be an incentive. Moreover, car owners pay a fixed monthly fee for having a private car, even if they do not use it. The decision to use a shared mobility service can therefore be a barrier.

The results of the short term show that the use of the shared e-car is more attractive than the use of the shared e-moped and the shared e-bike for commuting trips for realistic operating costs. The share of the use of the shared e-bike is significant for commuting trips. Moreover, the preference for using the shared e-bike increases with a denser mobility hub grid plan. While, in the long run, car owners prefer full shared e-car use as a substitute for the least used private car, see section 6.3.2. Hence, the use of the shared mobility services for commuting trips differs from the preference of the use of shared mobility services in the long term.

In both the short and long term, the density of mobility hubs in the built-up area is an important factor. A higher mobility hub density leads to an increase in the willingness to use shared mobility services and the willingness to give up the private car. A higher mobility hub density also leads to an increase in the preference for the shared e-car and e-bike, see table E.7. A transition from car movements to more active travel movements, such as bicycle movements, can be stimulated by a higher mobility hub density. Nevertheless, the preference for the use of the shared e-car for car owners remains in the long run.

The operating costs of shared mobility services are also an important factor for their use in the short and long term. Reducing the operating costs can make the use of shared mobility services for work-related trips more preferred and increase the willingness to give up the private car. However, proportional reduction of the original operating costs for the three shared mobility services only increases the preference for the use of the shared e-car and not that of the shared e-moped and shared e-bike for commuting trips. The preference for the use of the shared e-moped and shared e-bike for commuting trips can be increased when the operating costs for both are reduced or when the operating costs for the shared e-car are increased.

All in all, the models have shown that mobility hubs can actually have an effect on car use and car ownership under defined conditions. If the goal of a municipality is to make a transition to less car use and less car ownership, a dense network of mobility hubs is desirable. For a city centre a high density mobility hub grid plan is advisable and for both the suburban and rural area an intermediate density mobility hub grid plan is advisable. In reality, for the city of Delft a mobility hub configuration for the entire city could resemble as shown in figure 7.7. The yellow areas around the dots, representing the mobility hub, have a 1-minute walking time to mobility hubs. The blue areas have a 2-minute walking time to mobility hubs, while the pink area is a 3-minute walking time to mobility hubs. The rest of the areas have a 5-minute walking time to mobility hubs. In this figure it is clearly visible that a high density hub grid plan is extreme, whereas an intermediate density hub grid plan is more conceivable to realise.

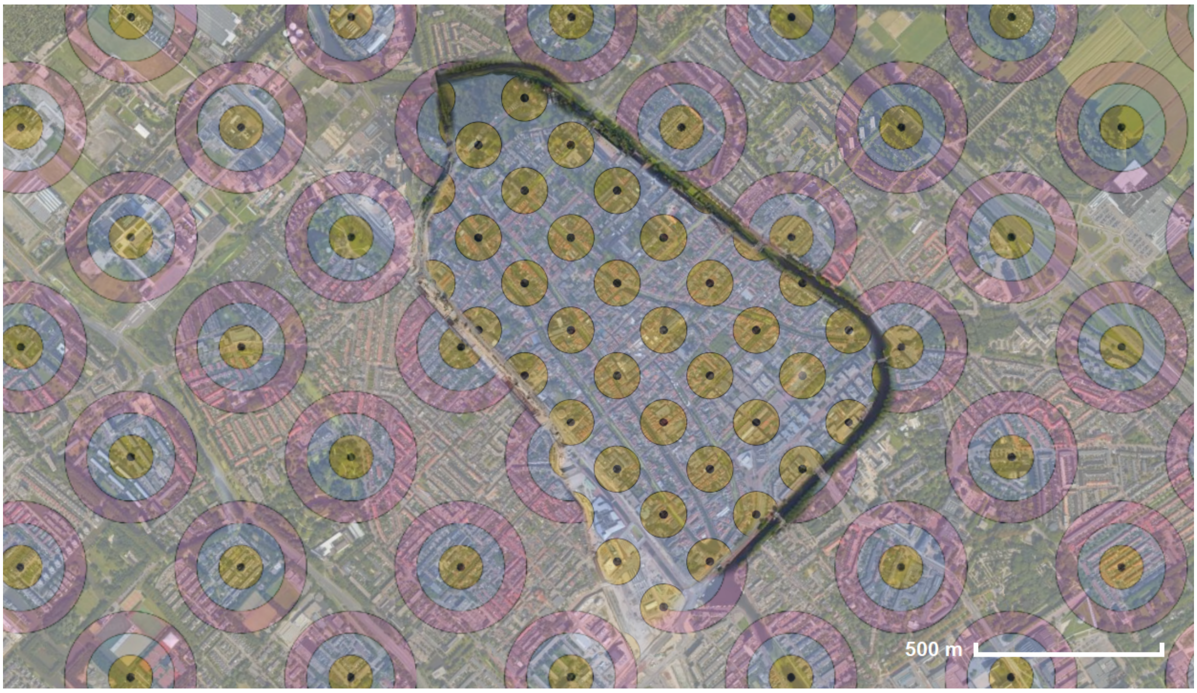


Figure 7.7: Visualisation of the city of Delft with high and intermediate density hub grid plans.

8

Conclusions, discussions, and recommendations

The main findings and the answer to the research question are discussed in section 8.1. Afterwards, the results are compared with the literature, the design is discussed and the limitations are discussed in section 8.2. Finally, the recommendations for transport engineering companies and further research are discussed in section 8.3.

8.1. Conclusions

In Dutch cities, car use and car ownership is too high. Offering shared mobility services might lead to a reduction in car use and private car ownership. Dutch municipalities are interested in offering shared mobility services at fixed locations, the so-called mobility hubs. However, the actual effects of mobility hubs on car use and car ownership are not known. Therefore, the purpose of this thesis was to examine the effects of mobility hubs on car use and car ownership. Besides the academic relevance, it is also important for Dutch municipalities to know the potential impact of mobility hubs. Local governments can focus on the development of mobility hubs in order to initiate a transition to a cleaner and more efficient transport system. To explore the underexposed effects of mobility hubs, the following main research question was formulated:

What factors explain people's willingness to use shared mobility alternatives in mobility hubs for trips and the willingness to give up the least used private car, and to what extent?

In the Netherlands, the majority of shared mobility services found in cities are already electrically powered. In view of the future where electric transport is likely to be the norm, this research focused on electrically powered shared mobility modes offered in mobility hubs. Based on the presence in the Dutch transport system, it is assumed that in mobility hubs shared e-cars, shared e-mopeds and shared e-bikes are present.

Problems of high car use and car ownership exist in all areas of the Randstad, and municipalities are interested in mobility hubs in order to mitigate these problems. Therefore, this research focused on both the effects of mobility hubs in city areas and non-city areas. The city areas consist of the city centre and suburban area, whereas the non-city areas consist of rural areas.

Factors that might influence the mode choice were classified into factors related to the traveler, factors related to the traveler's living environment and factors related to the trip. Based on the interviews with experts, only the most relevant factors were selected, which resulted in the conceptual framework. Based on the conceptual framework, two stated choice experiments were designed to examine the impact of the factors on car use and car ownership. The first experiment deals with the effects of the selected factors on car use for commuting trips. These effects are called the short-term effects. The second experiment deals with the effects of the selected factors on car ownership. These effects are called the long-term effects.

The data of the survey including the choice data were analysed using two techniques. The descriptive statistics describe the characteristics of the sample and the choice distributions in the two experiments. Discrete choice modelling is used to gain insights into the impact of the factors on people's willingness to use mobility hubs and give up the private car.

The sample of respondents originated mainly from the Randstad, so the results of this study only apply to people living in cities and areas in the Randstad. Almost all respondents are familiar with shared mobility services and that the respondents who used those services evaluated the use of the services very well.

The results of the discrete choice models for the short-term mode choice experiment provided interesting new insights. A positive preference for the use of the shared e-car over the private car for commuting trips was found. However, the decision to opt for a shared e-car for commuting trips depends on various factors. For short distances of 7.5 kilometres to work, respondents living in households with one or two cars are more willing to use a shared mobility alternative than respondents living in households with three cars or more. Besides, residents of a city centre (and suburban area) are more likely to use a shared e-car than residents of a rural area for the same short distances of 7.5 and 22.5 kilometer to work. The trip costs for the commuting trip are important. The sensitivity of the trip costs for the shared e-car is higher than that of the shared e-moped and the shared e-bike, implying that for an equal increase in trip costs, the shared e-car generates higher disutilities than the shared e-moped and shared e-bike. Interesting insights were also obtained for walking times. Respondents assess the access time and egress time for a trip with an alternative almost the same. A trend, however, can be discerned between the various alternatives. For distances of 7.5 and 22.5 kilometres to work, the sensitivity to walking time seems to be highest for the shared e-bike, followed by the shared e-moped. While the results showed that the walking times of the private car are almost equally sensitive to the walking times of the shared e-car. For long distances of 45 and 75 kilometres to work, the respondents seemed to assess the walking times for the private car and the shared e-car the same.

The results for the long-term mode choice experiment also provided interesting new insights. There appeared to be a positive preference for the mobility hub over the private car, however, the decision to give up the private car depends on several factors. Respondents who live in a household with one or two cars are more likely to give up the least used car than respondents who live in a household with three cars or more for a low monthly use of 500 kilometre of the private car. In addition, respondents with a monthly car use of 500 and 1500 kilometre and living in a city centre are more likely to give up the least used private car than respondents living in a rural area. For the same monthly use, the model shows that the sensitivity to an increase in walking time from home to a mobility hub is greater than that of to the private car, implying that for an equal increase in walking time, the mobility hub generates higher disutilities than the private car. Respondents are sensitive to the monthly costs that have to be paid for the use of the mobility hub. Sensitivity to operating costs is highest for the shared e-car, and thus higher than for the shared e-moped and shared e-bike. This may be related to the preference of car owners to use the shared e-car. Car owners who are willing to give up the least used private car and start using mobility hubs have a preference for full use of the shared e-car, and little preference for using the shared e-moped and shared e-bike.

Since the impact of the various factors on car use and car ownership was determined, the effect on car use and car ownership could be determined for the focus areas. These focus areas were a city centre, a suburban area and a rural area in the Randstad in the Netherlands. Based on the objectives of Dutch municipalities, strategies were examined to what extent these strategies affect private car use and car ownership. This research considered three types of mobility hub grid plans and pricing strategies. The willingness to use shared mobility services for commuting trips is slightly greater in a city centre and suburban area than in a rural area. Therefore, the reduction in private car use in the city centre and suburban area is slightly greater than in the rural area. Furthermore, a higher mobility hub density and a reduction of the operating costs of the shared mobility services lead to a larger reduction of private car use. The preference for the use of the shared e-car as an alternative to the private car is high. For commuting trips there is some preference for the use of shared e-bikes, and hardly any preference for the use of shared e-mopeds. Since the use of the shared e-car is attractive for car owners, mobility hubs will not lead to a large decrease in the number of car movements. The willingness to give up the least used car is highest for residents of the city centre, followed by those of the suburban area and is lowest in those of the rural area. Furthermore, a higher density of mobility hubs and a reduction in operating costs of the shared mobility services lead to an additional reduction in car ownership in the focus areas. The effects on the number of cars per household in the district are greatest in the city centre, followed by the suburban area and by far the least in the rural area. In both the short term and the long term, the density of mobility hubs is an important factor. A higher mobility hub density increases the willingness to use shared mobility services and also increases the willingness to give up the least used private car. Moreover, the operating costs of the shared mobility services are also important factors. The reduction of operating costs increases the willingness to use shared mobility services for commuting trips, and also increases the willingness to give up the least used private car.

This research has contributed to addressing a part of the research gap of the unexplored decision-making process with regard to the acceptance of mobility hubs. The research revealed that the potential of mobility hubs on car use and car ownership differs per type of residential area. The walking times to a mobility hub and private car are important factors determining the willingness to use shared mobility services and the willingness to give up the private car. On top of that, the operating costs of the shared mobility services are important factors on the willingness to use the services as well. Therefore, in order to stimulate a transition to reduced car use and car ownership, it is important to decide on the mobility hub density for a residential area and operating costs for the shared mobility services.

8.2. DISCUSSIONS

The results of this research are compared with the literature in section 8.2.1. After which, the research design is discussed in section 8.2.2. The limitations of this study are discussed in section 8.2.3.

8.2.1. COMPARISON WITH LITERATURE

A Dutch study showed that as a result of a shared car initiative, almost one-third of car-sharers would give up their car. Car ownership per household went from 1 car per household to 0.7 cars per household [Nijland et al., 2015]). This study showed that for a suburban area with car ownership of 1 car per household, the effect of mobility hubs on car ownership went to 0.68 cars per household for a low density mobility hub grid. A low density mobility hub grid is a grid plan with a maximum distance of 10 minutes from a household to a mobility hub. The effect of free floating shared cars is therefore almost equal to the effect of station-based shared mobility modes in mobility hubs with a low density hub grid.

Another study in the Netherlands shows that city centre residents are not willing to use shared mobility services in the long term, but rather in trying out the services [Fioreze et al., 2019]. Moreover, the adoption rates are low. The results of this research show just the opposite. The adoption rates are high in all focus areas, see chapter 7. Moreover, the scenario analyses show that in the long run more respondents will give up their car than want to use it for commuting trips.

The results of the models and the scenario analysis for the three focus areas show that the willingness to use shared mobility services and to give up the private car is highest in city centres. The willingness is higher there than in suburban and more rural areas. The pilot project in Sweden shows the same results [Strömberg et al., 2018]. In Gothenburg, the adoption rate for the use of shared mobility services of respondents living in city centres is higher than respondents living in suburban areas. However, it must be said that it is difficult to compare two residential areas between two countries.

8.2.2. RESEARCH DESIGN

For the design of the stated choice experiments, more attention could have been paid to the attributes and attribute levels. The attribute levels for the operating costs of the shared mobility alternatives were quite extreme. This made it easy for respondents to make a choice. The high adjusted rho-square of the models for the short-term mode choice experiment might be an explanation for this. Since the attribute levels for the operating costs were extreme, it might have had an effect on the assessment of the other attributes. Due to the extreme attribute levels of the operating costs, it might be that the choice was mainly made on that attribute while there was less focus on the other attributes.

For the design of the stated choice experiment, the attribute levels of the operating costs of the shared e-moped were 0.0753, 0.2259 and 0.3765 euro per kilometre. On this range, the alternative specific parameters for the operating costs of the shared e-moped is reliable for both short term and long term effects. In the scenario analyses for the three focus areas in chapter 7, it became clear that a realistic operating cost for the shared e-moped in the Netherlands is 0.489 euro per kilometre. The operating cost used for the shared e-moped in the scenario analyses was therefore outside the range at which the alternative specific parameter is reliable. Nevertheless, the actual operating cost of the shared e-moped is not far from the reliable range and therefore does not have major implications.

In the different levels of the usage scenario attribute, the share of the shared e-moped was larger than that of the shared e-bike. In the analyses of the three focus areas it turned out that the shared e-moped does not have an important share in commuting trips to replace the private car, and that the share of the shared e-bike is larger than that of the shared e-moped. The usage scenario levels might have been classified differently with the knowledge of this research, in which the share of the shared e-bike was larger than that of the shared e-moped.

For the sensitivity of the operating costs of the shared e-bike, no clear trend can be seen and, moreover, a remarkably positive utility contribution for monthly travel distances of 500 and 1500 kilometres. However, this would imply that with an increase of the operating costs of the shared e-bike, the preference for the mobility hub alternative increases. A reason for this could be caused by the usage scenario attribute in the choice situations. Namely, if the choice situation consisted of purely shared e-car use, the operating costs of the shared e-bike (and thus also the shared e-moped) were included while the travel costs were not shown. The choice situations can be found in appendix B.4.2. Another reason, could be caused as well by the usage scenario attribute in the choice situations. The share of the use of the shared e-bike was always low, resulting in a low contribution to the total monthly costs. Hence, it may have been the case that respondents made the choice mainly on the basis of the total monthly costs and also on the monthly travel costs of the shared e-car and the shared e-moped as these together provide a large share of the total monthly costs. This may have caused the three parameters for the travel costs for the shared e-bike for the three monthly travel distances not to be significant at the 95% confidence level.

The results of the choice models show that no distinction was made between access time and egress time. As the total travel time was given, there is a chance that respondents in the choice situations based their choice on the total travel time instead of the access times, trip times and egress times of the different alternatives.

8.2.3. Limitations

The use of stated choice experiments as a research method may have disadvantages. It is not clear whether the respondents' behaviour is the same as in the stated choice experiments [Ben-Akiva et al., 2019]. Since in some cases the respondents have no experience with the new shared mobility options, it is unknown whether respondents will behave in the same way after they have used the new mobility options in real life [Bruch and Mare, 2012]. The estimated models based on stated preference data overestimate the choice probabilities for new and non-existing options [Mcfadden, 2017]. Secondly, respondents assess the hypothetical situations at the individual level, whereas in reality respondents make mobility choices at the household level [Bruch and Mare, 2012].

In the experiments, the respondents are fully aware of the costs and walking times for the private car and the shared mobility services, while in reality this is not so clear. The respondents look at the attributes in a more rational way in the experiments. Whereas in reality, it is not so clear to people what they spend on private car use and car ownership. As a consequence, it's hard to predict if respondents would make the same decision in real life as they did in the experiments.

It is unknown what motivated the respondents to opt for the private car or for the mobility hub. As a result, from this research it cannot be directly indicated what adjustments to the shared mobility systems would be required to ensure a higher adoption rate for choosing the shared mobility services instead of the private car. The results of the choice models only show the sensitivity of the attributes on the utility contribution. Moreover, it is not clear what motivated the respondents to keep the least used private car.

In both experiments, the costs of an average private car in the Netherlands were used. This simplification led respondents to make choices based on this average private car. While in reality the costs associated with their least used private car could have been lower or higher. Moreover, these costs did not include depreciation costs or, for example, parking costs. For that reason, a follow-up research could consider a more realistic cost for the least used private car for the respondents. The survey would therefore have to be more personalised, which would make the research more expensive.

The goal of the recruitment process was to get a diverse sample of respondents from the Randstad area in the Netherlands. Eventually, the recruitment process succeeded in obtaining a large sample of respondents mainly from the Randstad area. The sample contains many young respondents, who are highly educated and who earn a lot. This could lead to an over or underestimation of the willingness to use shared mobility services compared to the real population.

8.3. RECOMMENDATIONS

The results of this research can be used for application to real situations and for further research. In section 8.3.1, it is discussed how transport engineering companies can use this research. Potential further studies based on this research are discussed in section 8.3.2.

8.3.1. RECOMMENDATIONS FOR PRACTICE

The findings of this research can be used by transport engineering companies and municipalities from the perspective of offering mobility hubs in neighbourhoods, and the potential of mobility hubs on car use and car ownership in different areas in the Randstad.

The first recommendation for Sweco concerns the approach to problems in neighbourhoods related to car ownership. The first step is to study the type of neighbourhood and its residents. It is important to assess whether the residents of a neighbourhood are the target group that is willing to make use of shared mobility services and to give up the private car. The type of neighbourhood determines the possible mobility hub grid plans. Then the objective of offering mobility hubs is important. The objective can be to reduce car ownership a little or to reduce it strongly. On the basis of the objective an appropriate density of mobility hubs in the neighbourhood can be selected. A higher density of mobility hubs has a stronger effect on reducing car ownership than a lower density. It is recommended, however, to first start with a lower density of mobility hubs. If a low density of mobility hubs does not have the desired effect, extra mobility hubs can be built to create a higher density of mobility hubs in a neighbourhood.

A second and last recommendation concerns parking standards and mobility hubs in city areas. In urban areas, mobility hubs will be located at current parking spaces of private cars as there is limited space elsewhere. This implies that normal parking spaces disappear in favour of fixed parking spaces that are exclusively dedicated to shared e-cars, e-mopeds or e-bikes. Offering mobility hubs therefore in itself leads to a reduction of the parking norm. This is a more passive way of lowering the parking norm. In the research, the sensitivity of respondents to the walking time for their own car was identified. Actively lowering the parking norm and offering mobility hubs in a neighbourhood can have an additional effect on reducing car ownership. These additional effects can be determined with the results of the models.

8.3.2. RECOMMENDATIONS FOR FURTHER RESEARCH

The focus of this research was to identify the main effects of mobility hubs, and therefore only the main attributes related to mobility hubs were added to the alternatives. Since a mobility hub is not only a parking lot but also a meeting place, an attribute can be added regarding the facilities at the mobility hubs. Furthermore, a parking cost attribute can be added for the private car in both the short- and long-term mode choice experiment. This might provide more insight into the interaction between parking costs and the willingness to give up the private car and use mobility hubs.

The impact of the availability of shared mobility modes in mobility hubs on car use and car ownership was not included in this study. The extent to which availability plays a role is therefore unknown. In addition, the number and type of mobility vehicles to be offered at the mobility hubs can be examined. The three proposed mobility hub grid plans could be the basis for exploring these issues.

A more personal survey about the costs of the private car and about walking times to the private car could give the respondents a better idea of the hypothetical situations. This can ensure that the respondents are better able to imagine themselves in the situations, which might make the choices more reliable. Furthermore, a paid survey can be carried out to obtain a sample of respondents that better reflects the population in the Randstad. This way, effects and willingness to opt for shared mobility services instead of the private car can be better estimated.

The shared mobility alternatives were electrically powered in both the short and long term mode choice experiment. The reason for this was that the majority of the shared mobility services in the Netherlands are electrically powered. An attribute related to the propulsion of the modes in the mobility hub can be added. The attribute levels can then be a combustion engine, electric engine or a combination of the two. Insight into the type of propulsion can give insight into the environmental and sustainable value on the motivation to opt for shared mobility services.

At the beginning of this research, Hely Hub only had operating mobility hubs in five cities in the Netherlands.

At present, there are already seven cities. In Amsterdam, they have gone from one location in June 2020 to seven locations in April 2021. This indicates that at the time of this research, the number of mobility hubs in the Netherlands is growing. Hely Hub is willing to provide traveler data for research purposes. Research based on revealed preference data makes a research more realistic and provides better insight into the actual effects of mobility hubs.

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A

EXPERT INTERVIEWS

During this research, several experts from different disciplines were consulted. The discussions were mainly used to generate background knowledge to give this research additional strength and depth.

Fanchao Liao, *Researcher at Delft University of Technology.*
Discussed: mode choice factors and their importance.

Niels Heeres, *Consultant at Sweco Netherlands.*
Discussed: mode choice factors and their importance.

Goncalo Homem de Almeida Correia, *Associate professor at Delft University of Technology*
Discussed: mode choice factors and their importance, stated choice experiments, choice modelling and other general research topics.

Jan Anne Annema, *Assistant professor at Delft University of Technology*
Discussed: Strategies for determining the effects of mobility hubs in the different focus areas, and other general research issues

Kjell Knippenberg *Operations Coordinator at Hely.*
Discussed: mobility hubs of Hely, and the associated issues.

Ross Ruiter, *Consultant Mobility at Sweco.*
Discussed: general issues related to the research.

Willem Scheper, *Consultant Mobility at Sweco.*
Discussed: general issues related to the research.

Jeroen Quee, *Consultant Sustainable Mobility and Parking at Sweco.*
Discussed: general issues related to the research, and walking times to and from mobility hubs and parking places.

B

EXPERIMENT DESIGN SUPPORTING DETAILS

In this appendix, the background basis for the stated choice experiments is explained. The travel costs for both the private car and shared mobility alternatives are explained. The travel costs consist of the operating costs and the monthly costs. After which the Ngene details are given, for the design of the two stated choice experiments.

B.1. PRIVATE CAR COSTS

The operating and monthly costs for the private car alternative are based on realistic costs of an average car. The characteristics regarding the private car alternative come from the Nibud. The Nibud is an independent organization that, among other things, conducts research into money related topics of consumers. The Nibud makes a classification on A,B,C and D-segment cars. However, this research uses an average of the four types of cars representing the private car alternative. The characteristics can be found in table B.1, which shows the costs for insurance, vehicle tax, maintenance and the kilometer price for A,B,C and D-segment and private car.

Table B.1: Costs of private cars. Adapted from: [Nibud, 2020]

Costs	**Component**	**A-segment**	**B-segment**	**C-segment**	**D-segment**	**Private car**
Monthly costs	Insurance	€ 42.00	€ 49.50	€ 60.50	€ 85.50	€ 59.38
	Vehicle Tax	€ 22.00	€ 33.50	€ 49.50	€ 68.50	€ 43.38
	Maintenance	€ 21.00	€ 21.00	€ 21.50	€ 21.00	€ 21.13
	Total monthly costs	**€ 85.00**	**€ 104.00**	**€ 131.50**	**€ 175.00**	**€ 123.88**
Operating costs	**Kilometre price**	**€ 0.1770**	**€ 0.2180**	**€ 0.2690**	**€ 0.3450**	**€ 0.2523**

In the choice situations of both the short-term and long-term mode choice experiment, respondents have to make a choice between the private car and the shared mobility alternatives. Since an average car in the Netherlands is used in this study, the operating and monthly costs do not vary. The costs for the commuting trip and the monthly travel costs are determined based on the price per travelled kilometre of € 0.2523 for the private car, see table B.1. Moreover, the monthly cost does not vary for the private car and is € 123.88 in the long-term mode choice experiments. This is independent of the monthly distance of 500, 1500 or 2500 kilometres. This is because it concerns the monthly fixed costs.

B.2. SHARED MOBILITY SERVICES COSTS

Currently there are several free-floating shared service providers in the Netherlands, however, this research focuses on station-based shared services. In this category, there is only one provider, on which the price for the use of the shared modes for this research is based. It concerns the Hely mobility hubs, operating in 7 Dutch cities in September 2020. The prices for the use of the Hely Hub can be found in figure B.1.

Both the monthly costs and operational costs for the shared mobility alternatives in mobility hubs for this study are based on the mobility hubs offered by Hely. However, Hely does not offer shared e-moped yet,

	HELY GO	HELY FLOW
MAANDELIJKSE KOSTEN Exclusief gebruikskosten	€ 0	€ 30 EERSTE MAAND 50% KORTING
TOEGANG HELY HUBS M.u.v. 'members only' locaties	Alle Hely Hubs in Nederland	Alle Hely Hubs in Nederland
MAXIMUM DAGTARIEF	Nee	Ja, per 24 uur max. 6 uur betalen
RESERVEREN	Tot 48 uur van tevoren gratis annuleren	Tot 4 uur van tevoren gratis annuleren
GEBRUIKSTARIEF Geen extra kosten voor brandstof en kilometers	Volledig tarief	Gereduceerd tarief, tot 40% korting per uur
EIGEN RISICO	€500	€250

TARIEVEN GEBRUIK

VOERTUIGEN Min. 1 uur afname, daarna afrekenen per minuut. Incl. brandstof- & kilometerkosten	€ PER UUR	€ PER UUR	€ PER 24 UUR
BIKE	€ 1,50	€ 1	€ 6
E-BIKE	€ 2,50	€ 1,50	€ 9
E-CARGO BIKE	€ 4,50	€ 3	€ 18
CITY CAR	€ 8,50	€ 6	€ 36
E-CITY CAR	€ 8	€ 5,50	€ 33
COMFORT CAR	€ 11	€ 7,50	€ 45
E-COMFORT CAR	€ 9	€ 6,50	€ 39

Figure B.1: Hely hub prices. Extracted from: [Hely, 2020]

therefore the operating costs for an e-moped is estimated between the operating costs for a shared e-car and a shared e-bike. For simplicity, the price to be paid per minute is converted into an average price per kilometre travelled for the shared e-car, e-moped and e-bike using the outcome of appendix B.3. Additionally, it is assumed that a monthly fee of 30 euro has to be paid for the use of the shared mobility alternatives from the mobility hub. This monthly cost can be seen as a subscription fee. The operating costs for the different shared mobility services can be found in table B.2.

Table B.2: Shared mobility service operating costs as input for the SCE.

	Operating costs		
Alternative	**Price per hour**	**Price per minute**	**Average price per kilometre**
Shared e-car	€ 9.00	€ 0.15	€ 0.1749
Shared e-moped	€ 6.00	€ 0.10	€ 0.2259
Shared e-bike	€ 2.50	€ 0.042	€ 0.1183

B.3. TRAVEL TIMES

The short-term mode choice experiment is categorised into four distances. In the stated choice experiments, respondents are presented with choice situations for only one distance, depending on the distance they have to travel from home to work. The travel times depend on the fixed distances and the mode and therefore do not vary. In other words, travel time is not an alternative specific attribute. Based on the distances, routes between a starting point and an end point were determined. The routes were found by trial and error with Google Maps. The routes were selected on the basis of a good mix of urban roads, provincial roads and motorways. This is shown in table B.3 for the four distances.

Table B.3: Routes as basis for the trips of the short-term mode choice experiments.

	Travel distance			
	7.5 km	**22.5 km**	**45 km**	**75 km**
From	Kastanjesingel 140, 3053 HP Rotterdam	Kastanjesingel 140, 3053 HP Rotterdam	Kastanjesingel 140, 3053 HP Rotterdam	Kastanjesingel 140, 3053 HP Rotterdam
To	Barbarakruid 2, 3068 SB, Rotterdam	Gemeneweg, 2391 NB Hazerswoude-Dorp	Nijverheidsbuurt 1-7, 3474 LA Zegveld	Van L.Stirumstraat, 1051 TS Amsterdam

Based on the four routes, the travel time for the four modes was determined using the ANWB route planner and Google Maps. Table B.4 shows the travel times for the four commuting trips with the four modes. Since the distances of 45 km and 75 km are not attractive for the shared e-moped and e-bike, and as it was expected that these two alternatives would not be chosen in the choice situations, these alternatives were not added to the experiments for these distances.

Table B.4: Travel times for the routes of the short-term mode choice experiments.

		Travel distance:			
Mode	**Attribute**	**7.5 km**	**22.5 km**	**45 km**	**75 km**
Private car	**Move time**	14 min	25 min	40 min	58 min
	Source	ANWB Routeplanner	ANWB Routeplanner	Google Maps	Google Maps
Shared e-car	**Move time**	14 min	25 min	40 min	58 min
	Source	ANWB Routeplanner	ANWB Routeplanner	Google Maps	Google Maps
Shared e-moped	**Move time**	16 min	53 min		
	Source	ANWB Routeplanner	ANWB Routeplanner		
Shared e-bike	**Move time**	20 min	67 min		
	Source	ANWB Routeplanner	ANWB Routeplanner		

B.4. NGENE DETAILS

This appendix provides the codes and the experimental designs generated with Ngene [ChoiceMetrics, 2018].

B.4.1. SHORT-TERM MODE CHOICE EXPERIMENTS

As described in chapter 5, two different experimental designs were generated for the short-term mode choice experiment. Appendix B.4.1 provides the design for the distances of 7.5 and 22.5 kilometres. Appendix B.4.1 provides the design for the distances of 45 and 75 kilometres.

7.5 AND 22.5 KILOMETRE FOR THE SHORT-TERM MODE CHOICE EXPERIMENT

Design
? Commuting trip: 7.5 km and 22.5 km
;alts = car, ecar, emoped, ebike
;rows = 36
;orth = sim
;block = 6
;model:
U(car) = b1 + b2*access_distance_car[0,1,2] + b3*egress_distance_car[0,1,2] /
U(ecar)= b4 + b5*access_distance_ecar[0,1,2] + b6*egress_distance_ecar[0,1,2] + b7*travel_cost_ecar[0,1,2] /
U(emoped) = b8 + b9*access_distance_emoped[0,1,2] + b10*egress_distance_emoped[0,1,2]
+ b11*travel_cost_emoped[0,1,2] /
U(ebike) = b12*access_distance_ebike[0,1,2] + b13*egress_distance_ebike[0,1,2] + b14*travel_cost_ebike[0,1,2]
$

Table B.5: Choice situations for the short-term mode choice experiment for 7.5 and 22.5 kilometre.

Choice situation	car.access_distance_car	car.egress_distance_car	ecar.access_distance_ecar	ecar.egress_distance_ecar	ecar.travel_cost_ecar	ed.access_distance_emoped	ed.egress_distance_emoped	emoped.travel_cost_emoped	ebike.access_distance_ebike	ebike.egress_distance_ebike	ebike.travel_cost_ebike	Block
1	2	1	2	2	1	1	2	2	1	1	2	2
2	1	1	2	2	2	2	1	1	2	2	1	5
3	1	2	1	1	1	1	2	2	2	2	1	6
4	2	2	1	1	2	2	1	1	1	1	2	3
5	0	2	1	2	2	0	2	0	0	1	1	5
6	1	2	1	2	0	2	0	2	1	0	0	5
7	1	1	2	1	2	0	2	0	1	0	0	3
8	0	1	2	1	0	2	0	2	0	1	1	6
9	0	2	2	1	0	1	1	0	2	0	2	5
10	2	2	2	1	1	0	0	1	0	2	0	2
11	2	1	1	2	0	1	1	0	0	2	0	3
12	0	1	1	2	1	0	0	1	2	0	2	3
13	0	2	0	0	2	2	0	0	2	2	0	3
14	2	2	0	0	0	0	2	2	0	0	2	6
15	2	0	2	2	2	2	0	0	0	0	2	4
16	0	0	2	2	0	0	2	2	2	2	0	1
17	1	0	2	0	0	1	0	1	1	2	2	6
18	2	0	2	0	1	0	1	0	2	1	1	6
19	2	2	0	2	0	1	0	1	2	1	1	1
20	1	2	0	2	1	0	1	0	1	2	2	4
21	1	0	0	2	1	2	2	1	0	1	0	6
22	0	0	0	2	2	1	1	2	1	0	1	3
23	0	2	2	0	1	2	2	1	1	0	1	1
24	1	2	2	0	2	1	1	2	0	1	0	1
25	1	0	1	1	0	0	1	1	0	0	1	1
26	0	0	1	1	1	1	0	0	1	1	0	4
27	0	1	0	0	0	0	1	1	1	1	0	5
28	1	1	0	0	1	1	0	0	0	0	1	2
29	2	1	0	1	1	2	1	2	2	0	0	4
30	0	1	0	1	2	1	2	1	0	2	2	4
31	0	0	1	0	1	2	1	2	0	2	2	2
32	2	0	1	0	2	1	2	1	2	0	0	5
33	2	1	1	0	2	0	0	2	1	2	1	4
34	1	1	1	0	0	2	2	0	2	1	2	1
35	1	0	0	1	2	0	0	2	2	1	2	2
36	2	0	0	1	0	2	2	0	1	2	1	2

45 AND 75 KILOMETRE FOR THE SHORT-TERM MODE CHOICE EXPERIMENT

Design
? Commuting trip: 45 km and 75 km
;alts = car, ecar,
;rows = 12
;orth = sim
;block = 6
;model:
U(car) = b1 + b2*access_distance_car[0,1,2] + b3*egress_distance_car[0,1,2] /
U(ecar)= b4*access_distance_ecar[0,1,2] + b5*egress_distance_ecar[0,1,2] + b6*travel_cost_ecar[0,1,2]
$

Table B.6: Choice situations for the short-term mode choice experiment for 45 and 75 kilometre

Choice situation	car.access_distance_car	car.egress_distance_car	ecar.access_distance_ecar	ecar.egress_distance_ecar	ecar.travel_cost_ecar	Block
1	2	1	2	2	1	1
2	1	1	2	2	2	2
3	1	2	1	1	1	1
4	2	2	1	1	2	2
5	0	2	1	2	2	0
6	1	2	1	2	0	2
7	1	1	2	1	2	0
8	0	1	2	1	0	2
9	0	2	2	1	0	1
10	2	2	2	1	1	0
11	2	1	1	2	0	1
12	0	1	1	2	1	0

B.4.2. LONG-TERM MODE CHOICE EXPERIMENTS

Design
? Giving up the car: 500, 1500, 2500 km
;alts = car, ehub
;rows = 36
;orth = sim
;block = 3
;model:
U(car) = b1 + b2*access_distance_car[0,1,2] /
U(ehub)= b3*access_distance_ehub[0,1,2] + b4*service_fee[0,1,2] + b5*TC_ecar[0,1,2] + b6*TC_emoped[0,1,2] + b7*TC_ebike[0,1,2] + b8*scenario[0,1,2,3]
$

Table B.7: Choice situations for the long-term mode choice experiment.

Choice situation	car.access_distance_car	ehub.access_distance_ehub	ehub.service_fee	ehub.tc_ecar	ehub.tc_emoped	ehub.tc_ebike	ehub.scenario	Block
1	1	2	2	1	1	2	0	2
2	2	1	1	2	2	1	2	5
3	1	2	2	2	2	1	0	6
4	2	1	1	1	1	2	1	3
5	0	2	0	0	1	1	3	5
6	2	0	2	1	0	0	1	5
7	0	2	0	1	0	0	1	3
8	2	0	2	0	1	1	0	6
9	1	1	0	2	0	2	3	5
10	0	0	1	0	2	0	3	2
11	1	1	0	0	2	0	2	3
12	0	0	1	2	0	2	2	3
13	2	0	0	2	2	0	0	3
14	0	2	2	0	0	2	2	6
15	2	0	0	0	0	2	0	4
16	0	2	2	2	2	0	1	1
17	1	0	1	1	2	2	3	6
18	0	1	0	2	1	1	1	6
19	1	0	1	2	1	1	1	1
20	0	1	0	1	2	2	0	4
21	2	2	1	0	1	0	3	6
22	1	1	2	1	0	1	3	3
23	2	2	1	1	0	1	2	1
24	1	1	2	0	1	0	2	1
25	0	1	1	0	0	1	0	1
26	1	0	0	1	1	0	2	4
27	0	1	1	1	1	0	0	5
28	1	0	0	0	0	1	1	2
29	2	1	2	2	0	0	3	4
30	1	2	1	0	2	2	1	4
31	2	1	2	0	2	2	1	2
32	1	2	1	2	0	0	0	5
33	0	0	2	1	2	1	3	4
34	2	2	0	2	1	2	3	1
35	0	0	2	2	1	2	2	2
36	2	2	0	1	2	1	2	2

C
SURVEY

In this appendix, the layout of the survey and its distribution are provided.

C.1. SURVEY

This appendix shows the final survey in Qualtrics. Only one route is shown for the survey. However, all the possible questions are included.

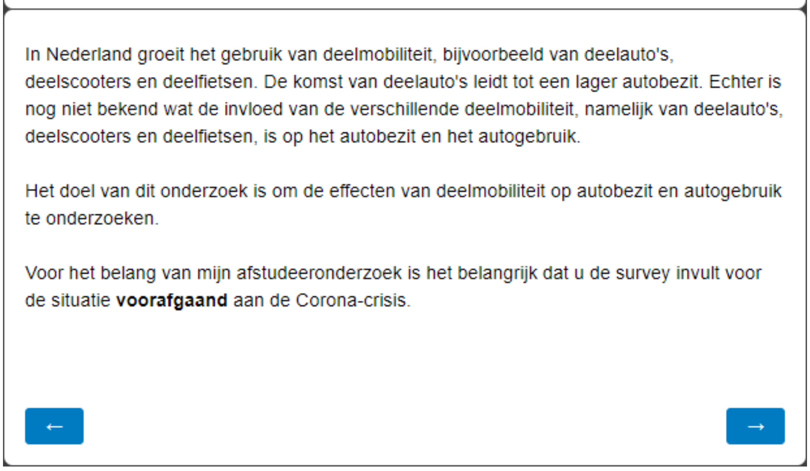
Deze enquête is onderdeel van mijn afstudeeronderzoek aan de Technische Universiteit Delft, in samenwerking met Sweco.

Uw deelname aan deze vragenlijst is geheel vrijwillig en anoniem en u kunt de vragenlijst op ieder moment verlaten. Uw data blijft vertrouwelijk en wordt volledig geanonimiseerd opgeslagen. De uitkomsten worden gebruikt voor het schrijven en online publiceren van mijn masterscriptie.

Deze enquête duurt ongeveer 8 minuten. Mocht u enige vragen hebben over de enquête of het verwerken van uw data, neem dan gerust contact met mij op via mathijs.franken@sweco.nl. Alvast veel dank voor uw bijdrage aan dit onderzoek!

Met vriendelijke groet,
Mathijs Franken

→



In Nederland groeit het gebruik van deelmobiliteit, bijvoorbeeld van deelauto's, deelscooters en deelfietsen. De komst van deelauto's leidt tot een lager autobezit. Echter is nog niet bekend wat de invloed van de verschillende deelmobiliteit, namelijk van deelauto's, deelscooters en deelfietsen, is op het autobezit en het autogebruik.

Het doel van dit onderzoek is om de effecten van deelmobiliteit op autobezit en autogebruik te onderzoeken.

Voor het belang van mijn afstudeeronderzoek is het belangrijk dat u de survey invult voor de situatie **voorafgaand** aan de Corona-crisis.

← →

Bent u in het bezit van een auto?

- Ja
- Nee

← →

Betreft het een privéauto of een leaseauto?

- Privéauto
- Leaseauto

← →

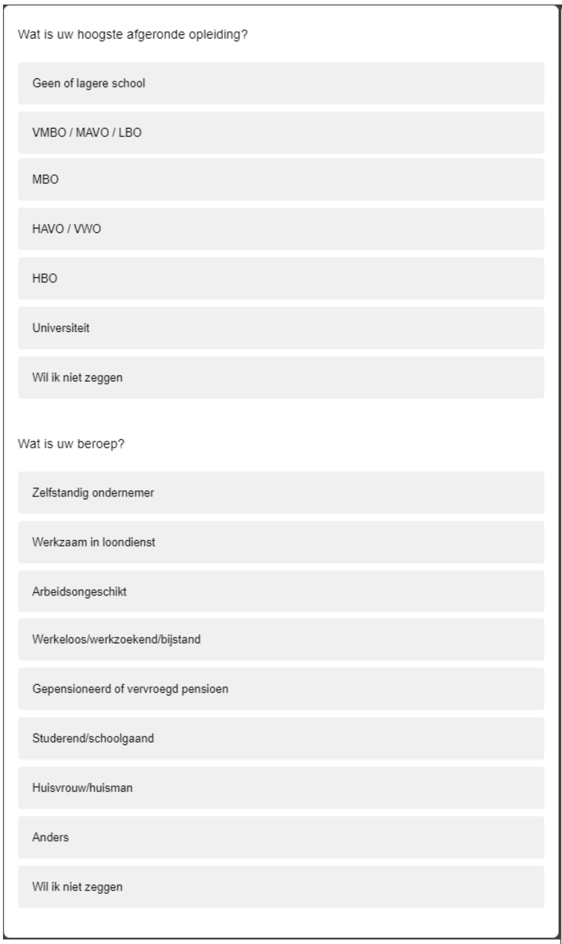
Hoe oud bent u?

- 18 tot en met 25
- 26 tot en met 35
- 36 tot en met 45
- 46 tot en met 55
- 56 tot en met 65
- 66 tot en met 75
- 75 jaar en ouder

Wat is uw geslacht?

- Man
- Vrouw
- Wil ik niet zeggen

← →

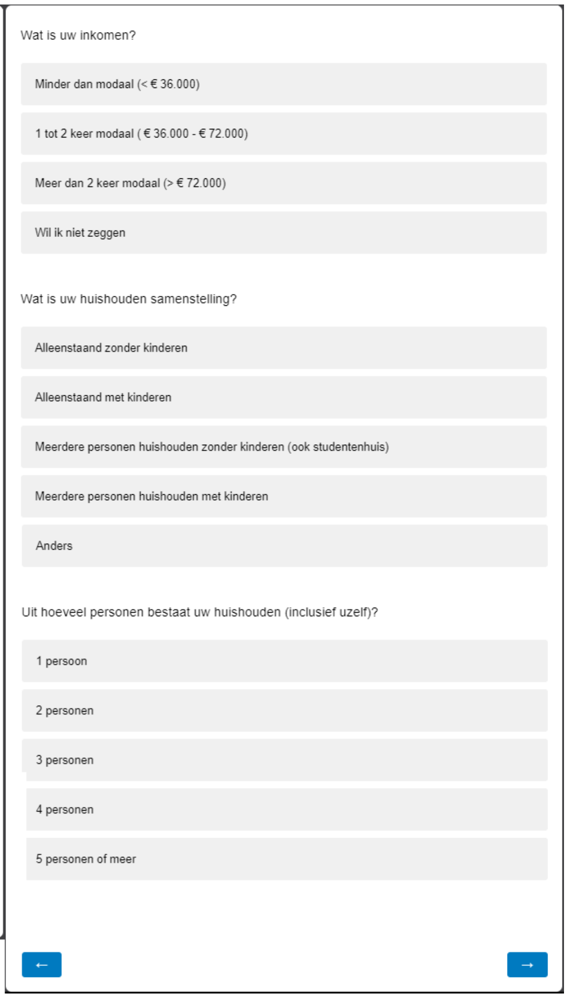


Wat is uw hoogste afgeronde opleiding?

- Geen of lagere school
- VMBO / MAVO / LBO
- MBO
- HAVO / VWO
- HBO
- Universiteit
- Wil ik niet zeggen

Wat is uw beroep?

- Zelfstandig ondernemer
- Werkzaam in loondienst
- Arbeidsongeschikt
- Werkeloos/werkzoekend/bijstand
- Gepensioneerd of vervroegd pensioen
- Studerend/schoolgaand
- Huisvrouw/huisman
- Anders
- Wil ik niet zeggen



Wat is uw inkomen?

- Minder dan modaal (< € 36.000)
- 1 tot 2 keer modaal (€ 36.000 - € 72.000)
- Meer dan 2 keer modaal (> € 72.000)
- Wil ik niet zeggen

Wat is uw huishouden samenstelling?

- Alleenstaand zonder kinderen
- Alleenstaand met kinderen
- Meerdere personen huishouden zonder kinderen (ook studentenhuis)
- Meerdere personen huishouden met kinderen
- Anders

Uit hoeveel personen bestaat uw huishouden (inclusief uzelf)?

- 1 persoon
- 2 personen
- 3 personen
- 4 personen
- 5 personen of meer

← →

Hoe zou u uw directe leefomgeving omschrijven? (Woonomgeving binnen uw gemeente)

- Centrum
- Schil centrum (rand centrum)
- Rest van de bebouwde kom
- Buitengebied

Wat zijn de eerste 4 cijfers van uw postcode?

Bent u in het bezit van een eigen parkeerplek?

- Ja
- Nee

← →

Hoeveel auto's heeft u of uw huishouden?

- 1
- 2
- 3

Wat voor soort type auto heeft u? Indien u meer dan 1 auto heeft, kies dan het type auto die u het eerst zou opgeven.

- Mini klasse (Toyota Aygo, Volkswagen Up! of vergelijkbaar)
- Compacte klasse (Volkswagen Polo, Renault Clio of vergelijkbaar)
- Kleine midden klasse (Ford Focus, Volkswagen Golf of vergelijkbaar)
- Midden klasse (Volkwasgen Passat, Audi A4 of vergelijkbaar)
- Hogere middel klasse of hoger (Audi A6, Mercedes E-klasse of vergelijkbaar)

Gebruikt u de auto voor werkgerelateerde ritten?

- Ja
- Nee

← →

Werkt u parttime of fulltime?

- Parttime
- Fulltime

Hoeveel dagen per week gebruikt u de auto voor werkgerelateerde ritten?

- Minder dan 1
- 1
- 2
- 3
- 4
- 5

Hoeveel kilometer moet u gemiddeld reizen **van uw huis naar werk?** (Enkele reis)

- 0 - 15 kilometer
- 15 - 30 kilometer
- 30 - 60 kilometer
- 60 - 90 kilometer
- Meer dan 90 kilometer

Hoeveel kilometer rijdt u maandelijks in totaal met uw privéauto? (**Zowel privé als werkgerelateerde ritten**)

- Tussen 0 en 1000 kilometer
- Tussen 1000 en 2000 kilometer
- 2000 kilometer of meer

← →

De elektrische deelauto

Een deelauto is een huurauto die u voor een beperkt tarief ook voor enkel ritje kunt huren en vaak niet per sé op dezelfde plek hoeft in te leveren. Sommige deelauto's hebben een slim slot dat u met een app of code kunt ontgrendelen waarna u er mee kunt wegrijden.

Hoe bekend bent u met het concept deelauto?

- Ik heb wel eens een deelauto gebruikt
- Ik heb van deelauto's gehoord maar nooit een gebruikt
- Ik heb nog nooit van deelauto's gehoord

← →

Hoe was, over het algemeen, uw deelauto ervaring?

Zeer ontevreden	Ontevreden	Neutraal	Tevreden	Zeer tevreden

← →

De elektrische deelscooter

Een deelscooter is een huurscooter die u voor een beperkt tarief ook voor enkel ritje kunt huren en vaak niet per sé op dezelfde plek hoeft in te leveren. Sommige deelscooters hebben een slim slot dat u met een app of code kunt ontgrendelen waarna u er mee kunt wegrijden.

Hoe bekend bent u met het concept deelscooter?

- Ik heb wel eens een deelscooter gebruikt
- Ik heb van deelscooters gehoord maar nooit een gebruikt
- Ik heb nog nooit van deelscooters gehoord

← →

De elektrische deelfiets

Elektrische deelfietsen hebben een elektrische trapondersteuning (motor) waardoor het fietsen gemakkelijker wordt voor de bestuurder.

Een elektrische deelfiets is een huurfiets die u voor een beperkt tarief ook voor enkel ritje kunt huren en vaak niet per sé op dezelfde plek hoeft in te leveren. Sommige deelfietsen hebben een slim slot dat u met een app of code kunt ontgrendelen waarna u er op kunt fietsen.

Hoe bekend bent u met het concept elektrische deelfiets?

- Ik heb wel eens een deelfiets gebruikt
- Ik heb van deelfiets gehoord maar nooit een gebruikt
- Ik heb nog nooit van deelfiets gehoord

← →

Het volgende gedeelte van de enquête bestaat uit een keuze-experiment.

Het keuze-experiment bestaat uit verschillende **hypothetische situaties** waarin u gevraagd wordt een keuze te maken voor de verschillende vragen.

← →

In het volgende deel van deze enquête moet u een keuze maken welke vervoerswijze u zou kiezen voor uw **woon-werkverkeer** ritten.

De **eigen auto** optie stelt uw huidige auto voor.

← →

Tijdens het keuze experiment krijgt u 6 keer een keuze voorgelegd. Bij elke vraag zijn er 4 opties, waaruit u kunt kiezen.

Voor iedere optie staan de loopafstand, reistijd en reiskosten aangegeven. Deze variëren per keer dat u een keuze maakt.

Het voorbeeld hieronder laat de looptijd, reistijd en reiskosten zien voor de deelauto optie.

	Elektrische deelauto	
Looptijd van huis naar voertuig (minuten)	8 min	Looptijd van huis naar voertuig
Reistijd (minuten)	14 min	Reistijd voor totale rit met elektrische deelauto
Looptijd van parkeerplaats naar werk (minuten)	8 min	Looptijd van parkeerplaats naar werk
Totale reistijd (minuten)	30 min	
Reiskosten	€ 1,58	Reiskosten voor de totale reis met de elektrische deelauto

Klik op de volgende-pijl om het keuze experiment te starten.

← →

De voorgestelde deelvoertuigen kunnen eenvoudig, vaak via een app, **gereserveerd** en **geopend** worden. De looptijd van uw huis naar een deelvoertuig hangt af van de **beschikbaarheid** van het voertuig in de buurt van uw huis.

← →

Stel dat u **7,5 kilometer** moet reizen naar uw werk.

Kiest u voor een deelvoertuig of gebruikt u uw eigen auto voor het woon-werkverkeer, maak uw keuze aan de hand van de onderstaande gegevens:

	Eigen auto	Elektrische deelauto	Elektrische deelscooter	Elektrische deelfiets
Looptijd van huis naar voertuig	8 min	8 min	5 min	5 min
Reistijd	14 min	14 min	16 min	20 min
Looptijd van parkeerplaats naar werk	5 min	8 min	8 min	5 min
Totale reistijd	27 min	30 min	29 min	30 min
Reiskosten	€ 1,87	€ 1,29	€ 2,79	€ 1,46

Welk vervoersmiddel zou u voor uw woon-werkverkeer kiezen als deze diensten bij u in de buurt beschikbaar komen?

Eigen auto

Elektrische deelauto

Elektrische deelscooter

Elektrische deelfiets

→

Het volgende gedeelte van de enquête bestaat uit een keuze-experiment.

Het keuze-experiment bestaat uit verschillende **hypothetische situaties** waarin u gevraagd wordt een keuze te maken voor de verschillende vragen.

← →

In Nederland groeit het gebruik van deelmobiliteit, bijvoorbeeld van deelauto's, deelscooters en deelfietsen. Deze modaliteiten worden op verschillende locaties (vaak in de stad en vlakbij OV-knooppunten) aangeboden en kunnen eenvoudig, vaak via een app, worden gebruikt.

In Nederland wordt onderzoek gedaan naar het plaatsen van **mobiliteitshubs** in woonwijken en minder stedelijke omgevingen. In mobiliteitshubs worden **elektrische deelauto's, elektrische deelscooters en elektrische deelfietsen** vanuit 1 centrale locatie aangeboden. Op deze manier kan de reiziger kiezen welke modaliteit het beste bij hem of haar past.

Voor het leveren van deze service zal de gebruiker **maandelijks een klein bedrag** moeten betalen om gebruik te maken van de deelvoertuigen. De deelvoertuigen zijn gebonden aan **vaste plekken**. In dit experiment zijn de aangeboden deelvoertuigen allemaal **elektrisch**. De deelvoertuigen moeten altijd opgehaald en terug gebracht worden naar dezelfde mobiliteitshub bij het vertrek of een andere mobiliteitshub bij de bestemming. Dit kan ook een mobiliteitshub in een andere stad zijn.

← →

In het volgende deel van deze enquête moet u een keuze maken of u uw eigen auto zou opgeven, en de mobiliteitshubs zal gebruiken voor al uw ritten.

Veronderstel dat alle voertuigen die in de mobiliteitshub aangeboden worden **elektrisch aangedreven** zijn en altijd **beschikbaar** zijn.

De aangegeven **scenario** in de experimenten stelt het **gebruik van de mobiliteitshub** voor.

De **eigen auto** optie stelt uw huidige auto voor.

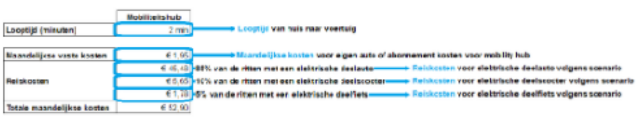
← →

Tijdens het keuze experiment krijgt u 6 keer een keuze voorgelegd. Bij elke vraag zijn er 2 opties, waaruit u kunt kiezen.

Voor iedere optie staan het scenario, de looptijd, maandelijkse vaste kosten en reiskosten aangegeven. Deze variëren per keer dat u een keuze maakt.

In de vragen krijgt u verschillende scenario's te zien. U dient het aangegeven scenario op te volgen.

Het voorbeeld hieronder laat de looptijd, maandelijkse vaste kosten en reiskosten zien voor de mobiliteitshub optie.



Klik op de volgende-pijl om het keuze experiment te starten.

← →

Stel dat u **500 kilometer per maand** rijdt in uw eigen auto.

Stelt u zich voor dat u de ritten met voertuigen uit de mobiliteitshub als volgt uitvoert:
85% van de ritten met een elektrische deelauto, 10% met een elektrische deelscooter, en 5% met een elektrische deelfiets

Houdt u zich vast aan uw eigen auto of kiest u voor de mobiliteitshub, maak uw keuze aan de hand van de onderstaande informatie:

	Eigen auto	Mobiliteitshub	
Looptijd (minuten)	8 min	5 min	
Maandelijkse vaste kosten	€ 123,88	€ 30,00	
Reiskosten	€ 126,21	€ 74,35	**85% van de ritten met een deelauto**
		€ 11,29	**10% van de ritten met een deelscooter**
		€ 4,93	**5% van de ritten met een deelfiets**
Totale maandelijkse kosten	€ 250,09	€ 120,58	

Zou u in deze situatie uw eigen auto opgeven, en de mobiliteitshubs gebruiken voor al uw ritten?

Ja

Nee

→

Dit is het einde van deze vragenlijst. Met de knop "volgende" kunt u de vragenlijst inleveren. Mocht u nog vragen hebben, neem dan contact op met mij via mathijs.franken@sweco.nl

Veel dank voor uw bijdrage aan dit onderzoek

Met vriendelijke groet,

Mathijs Franken

→

Wilt u aan het einde van het onderzoek informatie ontvangen over de resultaten van het onderzoek? Zo ja, dan kunt u hieronder uw e-mail
adres achterlaten. Wanneer het onderzoek is afgerond, zal ik u op de hoogte brengen van de resultaten.
Heeft u nog vragen en/of opmerkingen? Zo ja, dan kunt u deze ook hieronder achterlaten.

Voor SurveyCircle-gebruikers (www.surveycircle.com): De Survey Code is: GJGM-HRBR-87MX-T9JS

← →

Bedankt voor uw tijd om aan deze enquête deel te nemen.
Uw antwoord is geregistreerd.

C.2. DISTRIBUTION

The survey was distributed through various channels. Appendix C.2.1 shows the post on social media channels. The flyer with the QR code attached can be found in appendix C.2.2.

C.2.1. SOCIAL MEDIA

The exact same post was shared on LinkedIn and Facebook. For that reason, only the LinkedIn post is included.

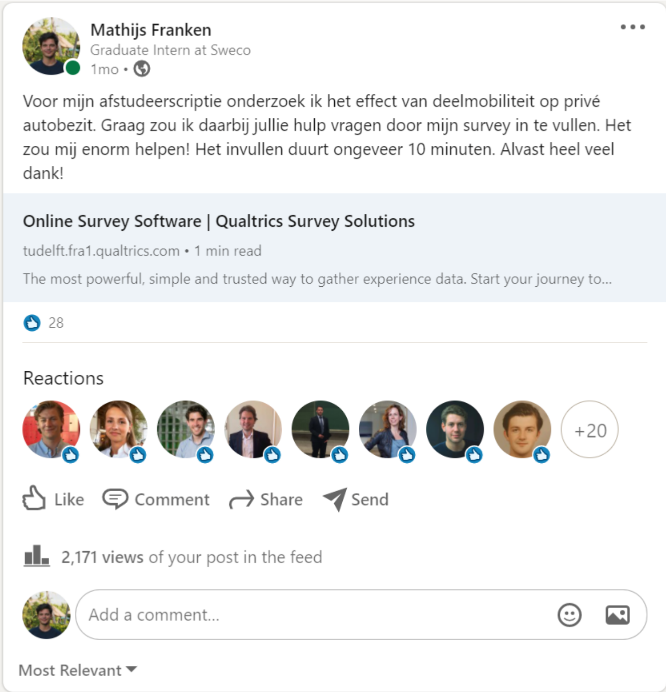


Figure C.1: LinkedIn post with link to survey.

C.2.2. FLYER

Figure C.2 shows the flyer that was distributed on the streets to people in order to get more different types of respondents.

Figure C.2: Flyer with QR code to survey.

D

MODEL RESULTS

This appendix provides background information on the survey and discusses survey results. Moreover, it gives the dummy codes that are used for the usage scenario attribute and socio-demographic variables.

D.1. MINIMUM REQUIRED

An indication of the minimum number of respondents for the various distances and experiments is calculated. The procedure is based on the equation 3.5. This can be found in table D.1.

Table D.1: Minimum required respondents

	Short-term mode choice experiment		**Long-term mode choice experiment**
	7.5 and 22.5 km	**45 and 75 km**	**All distances**
C	3	3	4
Q	6	4	6
A	4	2	2
N	**63**	**188**	**167**

For 7.5 and 22.5 kilometres in the short-term mode choice experiments, 63 respondents are needed for both categories. For 45 and 75 kilometres for the short-term mode choice experiments, 188 respondents are needed for both categories. For the long-term mode choice experiment, a minimum of 167 respondents are needed for the three monthly distances each. Therefore, 500 respondents for the survey are ideally needed for a reliable outcome following the rule of thumb. The large number of respondents required different ways of approaching respondents for the survey, see section 3.4.2.

D.2. CALCULATIONS

Based on the survey, the average distance to the private car is calculated and the respondents' evaluation of the shared mobility services. Finally, the number of cars per household is normalised.

D.2.1. WALKING TIME TO PRIVATE CAR

Table D.2 shows the frequency of the responses concerning the walk time from home to the least used private car. It turns out that on average, the sample of respondents walks about 2 minutes and 15 seconds to the least used private car.

D.2.2. EVALUATION OF SHARED MODES

Table D.3 shows the frequency of responses concerning the evaluation of the shared mobility services of the survey respondents. In the end, the shared e-moped is the best rated, followed by the shared e-car and least

Table D.2: Walking time distribution to private car of the sample.

Walking time to private car	Number of respondents
0 - 2 minutes	157
2 - 4 minutes	92
4 - 6 minutes	17
6 - 8 minutes	6
8 minutes or more	7

valued is the shared e-bike.

Table D.3: Evaluation of shared modes of the sample.

	shared e-car	shared e-moped	shared e-bike	Factor
Very dissatisfied	0	0	1.40%	1
Dissatisfied	1.10%	0.70%	1.40%	2
Neutral	8.80%	5.30%	16.10%	3
Satisfied	39.60%	37.10%	36.10%	4
Very satisfied	50.50%	57.00%	45.00%	5
Grade	**4.395**	**4.507**	**4.219**	

D.2.3. NUMBER OF CARS PER HOUSEHOLD

Only respondents with at least one car in the household were needed in this research. To be able to compare the sample properly, the sample should be compared with only households with at least one car. In table D.4, the percentage of households is normalised for only households with private cars.

Table D.4: Cars per household in the Netherlands [van Beuningen et al., 2012].

Variable	Category	Percentage NL	Normalized
Cars per household	No car	28.00%	
	One car	50.00%	68.49%
	Two cars	19.00%	26.03%
	Three or more cars	4.00%	5.48%

D.3. CHI-SQUARED TEST

A chi-squared test assesses whether two variables of nominal scale are independent of each other. The chi-square value is derived from the difference in the expected frequency and the observed frequency of the different categories. The expected values can be calculated by following the distribution of the sample as a whole. Equation D.1 determines the chi-squared value. The o_i are the observed counts, and the e_i are the expected counts.

$$\chi^2 = \sum_{i=1}^{k} \frac{(o_i - e_i)^2}{e_i} \tag{D.1}$$

In order to determine whether the sample differs from the Dutch population or the Randstad population, a chi-squared test was applied. This was done for gender, age, education level, income level, household size and the number of cars in the household. In the survey, some respondents did not answer questions about gender, income, educational level. The data from the sample was compared to CBS data. CBS data contains all information for residents of the Netherlands. CBS data therefore does not contain 'unkown' categories. For that reason, the answers to which no answer was given were removed for the chi-squared test. This way, it can be compared to the expected numbers. The results of the chi-squared tests can be found in table D.5, and the explanation below it.

The chi-square tests show that only for gender the difference between the sample and the Dutch population is not statistically significant at 95% confidence level. For age, educational level, income level, household size

Table D.5: Chi-square test results.

	Gender	Age	Education	Income	Household size	Cars in household
Chi-square	0.175	81.096	739.779	3703.043	143.938	379.434
df	1	2	2	2	2	2
P-value	0.6759	0.0001	0.0001	0.0001	0.0001	0.0001

and the number of cars in a household, the difference with the Dutch population is extremely statistically significant at 95% confidence level.

D.3.1. GENDER

The sample was compared to the population of the Randstad and the Netherlands. For gender, the sample is slightly better described by the population from the Randstad than from the whole of the Netherlands.

Table D.6: Observed and expected frequency for gender.

	Observed	Expected (Randstad)	Expected (Netherlands)
Man	279	283	284
Woman	293	289	288

The difference between the sample and the Randstad population is not considered statistically significant. The chi-square equals 0.112 with 1 degree of freedom and a P-value of 0.7380. While, the difference between the sample and the Dutch population is not considered statistically significant. The chi-square equals 0.175 with 1 degree of freedom and a P-value of 0.6759.

D.3.2. AGE

The sample was compared to the population of the Randstad and the Netherlands. For age, the sample is slightly better described with the population from the Randstad than from the whole of the Netherlands.

Table D.7: Observed and expected frequency for age.

	Observed	Expected (Randstad)	Expected (Netherlands)
18 - 35	162	218	161
36 - 65	364	264	279
66+	48	92	134

The seven age groups (see table 6.3) have been reduced to three groups. Namely 18 to 35 years, 36 to 65 years and 66 years and older. As can be seen in table D.5, the difference between the sample and the Dutch population is extremely statistically significant. The small P-value shows that the data obtained from the survey does not resemble the distribution expected with the Dutch population.

The difference between the sample and the Randstad population is considered to be extremely statistically significant. The chi-square equals 73.308 with 2 degrees of freedom and a P-value of 0.0001. While, the difference between the sample and the Dutch population is considered to be extremely statistically significant. The chi-square equals 81.096 with 2 degrees of freedom and a P-value of 0.0001.

D.3.3. EDUCATIONAL LEVEL

Table D.8: Observed and expected frequency for educational level.

	Observed	Expected
Low	8	162
Medium	71	221
High	492	188

The five educational level groups identified in table 6.4 were reduced to three groups according to [OCW, 2019]. These groups are categorised as low-educated, medium-educated and highly-educated. Low-educated includes primary education, VMBO, the first three years of HAVO/VWO, and MBO-1. Medium-educated includes senior year of HAVO/VWO and MBO-2 up to MBO-4. Higher education ultimately includes HBO and university education.

The difference between the sample and the Dutch population is considered to be extremely statistically significant. The chi-square equals 739.779 with 2 degrees of freedom and a P-value of 0.0001. The small P-value shows that the data obtained from the survey does not resemble the distribution expected with the Dutch population.

D.3.4. INCOME

Table D.9: Observed and expected frequency for household income level.

	Observed	Expected
0 - 36.000	117	420
36.000 - 72.000	275	124
72.000 or more	159	7

The difference between the sample and the Dutch population is considered to be extremely statistically significant. The chi-square equals 3703.043 with 2 degrees of freedom and a P-value of 0.0001. For the income level, the sample again deviates from reality (see table D.3). The difference between the sample and the Dutch population is extremely statistically significant.

D.3.5. HOUSEHOLD SIZE

The sample was compared to the population of the Randstad and the Netherlands. For household size, the sample is slightly better described by the population from the Netherlands than from the population of the Randstad.

Table D.10: Observed and expected frequency for household size.

	Observed	Expected (Randstad)	Expected (NL)
1 to 2 persons	279	442	409
3 to 4 persons	241	107	136
5 persons or more	54	25	29

The five groups as in table 6.6 for the household size were reduced to three groups. These are a small household (1 to 2 persons), a medium large household (3 to 4 persons) and a large household (5 persons or more). This results that the difference between the sample and the Dutch population is considered as extremely statistically significant. The small P-value shows that the data obtained from the survey does not resemble the distribution expected with the Dutch population.

The difference between the sample and the Randstad population is considered to be extremely statistically significant. The chi-square equals 261.564 with 2 degrees of freedom and a P-value of 0.0001. While, the difference between the sample and the Dutch population is considered to be extremely statistically significant. The chi-square equals 143.938 with 2 degrees of freedom and a P-value of 0.0001.

D.3.6. CARS IN HOUSEHOLD

Table D.11: Observed and expected for cars in household

	Observed	Expected
1 car	178	393
2 cars	339	149
3 cars or more	57	32

The difference between the sample and the Dutch population is considered to be extremely statistically significant. The chi-square equals 379.434 with 2 degrees of freedom and a P-value of 0.0001. The small P-value shows that the data obtained from the survey does not resemble the distribution expected with the Dutch population.

D.4. DUMMY CODES

The usage scenario attribute is dummy coded for 4 levels. In addition, the socio-demographic variables for the are coded with dummy codes for 2 and 3 levels. The dummy coding can be seen in tables D.12, D.13, D.14 and D.15. The variable of the number of cars per household consists of 3 and 2 levels, explained in section 6.3.1.

Table D.12: Usage scenario attribute dummy coding.

		Low	Mid	High
Usage scenario	Scenario Low	1	0	0
	Scenario Mid	0	1	0
	Scenario High	0	0	1
	Scenario Fully	0	0	0

Table D.13: Living environment attribute dummy coding.

		Center	Suburb
Living environment	Center	1	0
	Suburban area	0	1
	Rural area	0	0

Table D.14: Number of cars in household attribute dummy coding with three levels.

		One	Two
Number of cars in household	One car	1	0
	Two cars	0	1
	Three cars	0	0

Table D.15: Number of cars in household attribute dummy coding with two levels.

		One	Two or three
Number of cars in household	One car	1	0
	Two or three cars	0	0

E

RESIDENTIAL AREAS SUPPORTING DETAILS

This appendix provides information for typical Dutch cities, operating costs as input for the models and the results of the three focus areas on car use and car ownership.

E.1. TYPICAL DUTCH CITIES

In chapter 7, it is important to gain insight into car ownership for a typical city centre, suburban area and rural area. Insight is gained by analysing characteristics of three Dutch cities, which are Den Bosch, Delft and Gouda. After discussions with Sweco consultants, these three cities appeared to be representative of typical cities in the Randstad. Figures E.1, E.2 and E.3 show for Den Bosch, Delft and Gouda respectively how car ownership depends on the location in the city.

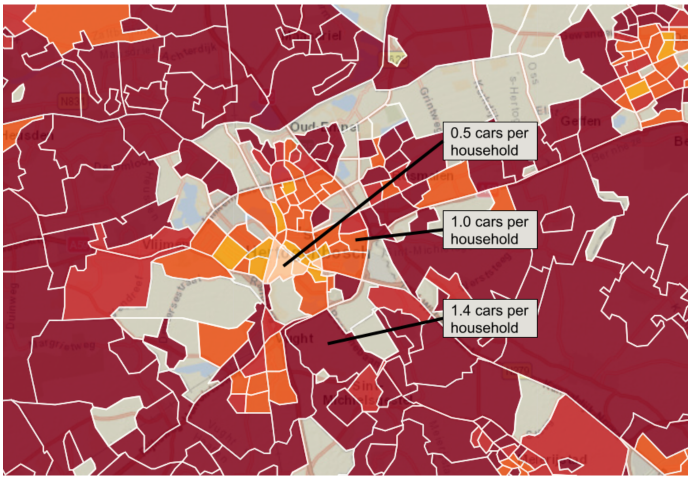


Figure E.1: Overview of car ownership rates for areas of Den Bosch. Adapted from: [CBS, 2016b]

Finally, on the basis of Den Bosch, Delft and Gouda, an average is taken for the car ownership per household for the city centre, suburban area and rural area as shown in table E.1.The number of cars per household is lower in densely populated areas than in sparsely populated areas [CBS, 2016b]. For a typical city centre the car ownership is 0.5 car per household. While for a suburban area, car ownership is 1.0 car per household. For a more rural area, this research assumes an average of 1.5 cars per household.

Using CBS data [CBS, 2018b], an estimate was made of the approximate number of households living in the indicated areas per square kilometre. This can be found in table E.2. In this study, it is assumed that a city centre of a Dutch city has 6000 households per square kilometre. A suburban area has 3000 households per square kilometre. Finally, this research assumes that there are 100 households per square kilometre in a rural area. This is based on the average of the three places, as shown in table E.2.

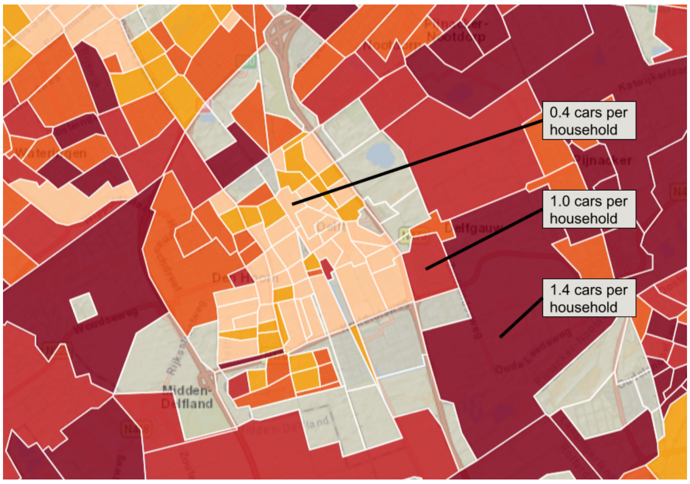


Figure E.2: Overview of car ownership rates for areas of Delft. Adapted from: [CBS, 2016b]

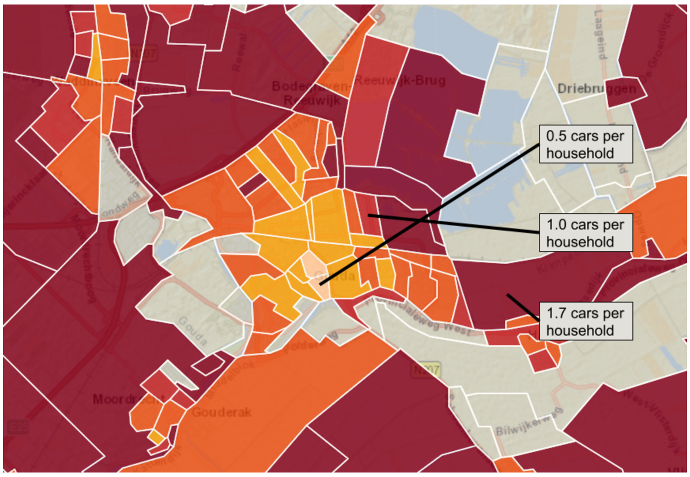


Figure E.3: Overview of car ownership rates for areas of Gouda. Adapted from: [CBS, 2016b]

Table E.1: Average number of cars per household in city centre, suburban area and rural area for Dutch cities

Dutch city	City centre	Suburban area	Rural area
Den Bosch	0.5	1.0	1.4
Delft	0.4	1.0	1.4
Gouda	0.5	1.0	1.7
Average	0.5	1.0	1.5

Table E.2: Overview of the amount of households per square kilometre for different areas. Adapted from: [CBS, 2018b]

Dutch city	City centre	Suburban area	Rural area
Den Bosch	5960	2960	210
Delft	7560	2380	40
Gouda	4380	3140	20
Average	5967	2827	90

E.2. OPERATING COSTS

As input for the models, it is necessary to have realistic values for the operating costs of shared e-car, e-moped and e-bikes.

E.2.1. SHARED E-CARS

There are several shared e-car operators in the Netherlands. For these operators, the costs per minute are converted into costs per kilometre travelled, as shown in table E.3. Based on this information, an average price per kilometre travelled is calculated. This average price is used as input for the models. The kilometre price for a shared e-car is therefore € 0.268 per kilometre travelled.

Table E.3: Price per kilometre for different shared e-car operators in the Netherlands. The average of the three providers is used as an input for the models.

	Hely Hub (VW GOLF)	**Sixt Share (VW GOLF)**	**Sixt Share (SEAT Mii)**	**Average**
Shared e-car	€ 0.175	€ 0.338	€ 0.292	€ 0.268

E.2.2. SHARED E-MOPEDS

In Dutch cities there are also several shared e-moped operators. Again, the prices per minute are converted into costs per kilometre travelled, as shown in table E.4. Based on this information, an average price per kilometre travelled is calculated. This average price is used as input for the models. The price per kilometre travelled for a shared e-moped is € 0.489.

Table E.4: Price per kilometre for different shared e-moped operators in the Netherlands. The average of the three operators is used as an input for the models.

	Hely Hub (expected)	**Check**	**Felyx**	**Average**
Shared e-moped	€ 0.226	€ 0.565	€ 0.678	€ 0.489

E.2.3. SHARED E-BIKES

There are many different shared e-bike operators in the Netherlands. The costs per travelled kilometre can be found in table E.5 for three different operators. Based on this information, an average price per kilometre travelled is calculated. This average price is used as input for the models. The average travel cost for one kilometre with a shared e-bike is € 0.123.

Table E.5: Price per kilometre for different shared e-bike operators in the Netherlands. The average of the three operators is used as an input for the models.

	Hely Hub	**Donkey Republic**	**Flickbike**	**Average**
Shared e-bike	€ 0.118	€ 0.156	€ 0.095	€ 0.123

E.3. RESULTS FOR THE FOCUS AREAS

The results of the short- and long-term effects can be found in section E.3.1 and E.3.2.

E.3.1. OUTCOMES SHORT TERM MODELS

The high density hub grid plan is only applied to the city centre. Table E.6 shows the effects on car use and use of shared mobility services for the different pricing strategies. The effect of reducing the operating costs of the shared mobility services is high on the willingness to use shared mobility services

Table E.6: High density hub grid plan results.

Focus area	**Alternative**	**Original operating costs**	**20% reduction of original operating costs**	**40% reduction of original operating costs**
City centre	Private car	63.8%	43.9%	24.5%
	Shared e-car	21.2%	40.1%	59.9%
	Shared e-moped	0.9%	1.7%	3.0%
	Shared e-bike	14.2%	14.4%	12.6%

The intermediate density hub grid plan is applied for the city centre, suburban area and rural area. In table E.7, the effects on car usage and the use of shared mobility services for the different pricing strategies are shown. The effects of reducing the operating costs for the shared mobility services are high for the three focus areas.

Table E.7: Intermediate density hub grid plan results.

Focus area	Alternative	Original operating costs	20% reduction of original operating costs	40% reduction of original operating costs
City centre	Private car	77.4%	59.8%	38.0%
	Shared e-car	15.2%	31.5%	53.0%
	Shared e-moped	0.6%	1.1%	2.1%
	Shared e-bike	6.9%	7.5%	6.9%
Suburban area	Private car	76.9%	59.4%	38.0%
	Shared e-car	15.3%	31.4%	52.2%
	Shared e-moped	0.2%	0.6%	1.3%
	Shared e-bike	7.6%	8.6%	8.6%
Rural area	Private car	78.8%	63.3%	43.7%
	Shared e-car	13.0%	27.0%	45.8%
	Shared e-moped	0.2%	0.4%	1.0%
	Shared e-bike	8.1%	9.2%	9.4%

The low density hub grid plan is applied for the suburban area and rural area. In table E.8, the effects on car usage and the use of shared mobility services for the different pricing strategies are shown. The effects of reducing the operating costs for the shared mobility services are high for the two focus areas.

Table E.8: Low density hub grid plan results.

Focus area	Alternative	Original operating costs	20% reduction of original operating costs	40% reduction of original operating costs
Suburban area	Private car	88.3%	76.9%	58.5%
	Shared e-car	8.8%	19.6%	37.3%
	Shared e-moped	0.1%	0.3%	0.7%
	Shared e-bike	2.8%	3.3%	3.5%
Rural area	Private car	89.7%	79.6%	63.3%
	Shared e-car	7.3%	16.7%	32.4%
	Shared e-moped	0.1%	0.2%	0.5%
	Shared e-bike	3.0%	3.5%	3.8%

E.3.2. OUTCOMES LONG TERM MODELS

The results of the models regarding the decision to give up the least used car in the household are summarised in table E.9. The differences between the focus areas with the different mobility hub grid plans and the pricing strategies are noticeable.

Table E.9: Overview of the share of households that would give up the least used private car for the different focus areas for the different strategies.

Focus area	Mobility hub grid plan	Original operating costs	20% reduction of original operating costs	40% reduction of original operating costs
City centre	High density	61.0%	71.6%	80.9%
	Intermediate density	50.3%	61.0%	71.8%
Suburban area	Intermediate density	46.9%	58.1%	69.2%
	Low density	32.1%	41.2%	52.0%
Rural area	Intermediate density	42.1%	52.9%	64.5%
	Low density	28.4%	36.7%	47.1%

The number of households and the number of cars per household are used to estimate the effects on the number of cars in the three focus areas. Data from CBS provides insight into the number of cars in the three focus areas, see table E.2. For a city centre it is assumed that 3000 households own one car. For a suburban area, it is assumed that 3000 households own one car. Finally, for a rural area it is assumed that 50 households own one car, and 50 households own two cars. Table E.10, provides information for the number of cars present in the three focus areas.

Table E.10: Number of households, number of cars per household and total number of cars for the three focus areas. See tables E.2 en E.1

	City centre	Suburban area	Rural area
Number of households	6000	3000	100
Cars per household	0.5	1.0	1.5
Total cars in that area	3000	3000	150

The effects on the number of cars in the three focus areas are shown in table E.11. For the city centre and suburban area, the effect on the number of cars is obvious. While for rural area the effect on the number of cars in the district is slightly different. Since there are households that own two cars, they still retain one car after giving up the least used one.

Table E.11: Effects on the number of cars in the focus areas.

Focus area	Mobility hub grid plan	Current situation	Original operating costs	20% reduction of original operating costs	40% reduction of original operating costs
City centre	High density	3000	1171	851	572
	Intermediate density	3000	1490	1169	845
Suburban area	Intermediate density	3000	1593	1257	923
	Low density	3000	2037	1764	1440
Rural area	Intermediate density	150	108	97	86
	Low density	150	122	113	103

Table 7.27 shows the effect on the total number of cars in the district owned by households living in the city centre, suburban area and rural area.

The effect on the reduction of the total number of cars can also be expressed in terms of car ownership per household. This can be found in table E.13. For the different focus areas with the mobility hub grid plans and pricing strategies, the difference compared to the current situation is presented.

Table E.12: Overview of the effect on the reduction of car ownership at neighbourhood level for the different focus areas for the different strategies.

Focus area	Mobility hub grid plan	Original operating costs	20% reduction of original operating costs	40% reduction of original operating costs
City centre	High density	61.0%	71.7%	80.9%
	Intermediate density	50.3%	61.0%	71.8%
Suburban area	Intermediate density	46.9%	58.1%	69.2%
	Low density	32.1%	41.2%	52.0%
Rural area	Intermediate density	28.1%	35.3%	43.0%
	Low density	18.9%	24.5%	31.4%

Table E.13: Overview of the effects on cars per household with different mobility hub grid plan and pricing strategies.

Focus area	Mobility hub grid plan	Current situation	Original operating costs	20% reduction of original operating costs	40% reduction of original operating costs
City centre	High density	0.50	0.20	0.14	0.10
	Intermediate density	0.50	0.25	0.19	0.14
Suburban area	Intermediate density	1.00	0.53	0.42	0.31
	Low density	1.00	0.68	0.59	0.48
Rural area	Intermediate density	1.50	1.08	0.97	0.86
	Low density	1.50	1.22	1.13	1.03

F

Scientific paper

Effects of e-mobility hubs in residential areas on car use and ownership: Stated choice experiments in the context of Dutch cities

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Abstract

This paper aims to explore the potential of mobility hubs to reduce car use and car ownership, and how this is affected by the car owner's characteristics, the trip characteristics and the car owner's living environment characteristics. To this end, two stated choice experiments were conducted and the data was analysed using extended multinomial logit models. The results showed that the shared e-car is preferred to the private car for commuting trips if the walking times and operational costs are attractive. The operational costs of shared mobility services and the walking distances to mobility hubs were found to be important factors for the use of shared mobility services. These two factors were also found to be important for the willingness to give up the private car and thus the choice for shared mobility services offered in mobility hubs for all trips. Sensitivity to operational costs was found to be higher for the shared e-car than for the shared e-moped and e-bike. Car owners preferred full e-car sharing if the private car was given up. Car owners had little preference for the use of shared e-mopeds and e-bikes. The density of mobility hubs in a residential area was found to have a strong impact on reducing car use and car ownership. Moreover, lowering the current operating costs was found to make the use of shared mobility services more attractive. The effects of mobility hubs on car use and car ownership were highest in the city centre, followed by the suburban area and lowest in a rural area.

Keywords: mobility hubs, shared mobility services, car use, car ownership

1 Introduction

Over the past few decades, the growth of the world's population has exploded. Next to this exorbitant growth, many countries also experience urbanization of the areas around and in cities. Problems associated with private cars can be found in many Dutch cities, from the city centre to the suburbs to the more rural areas, and as a result of strong urbanization, municipalities will face greater mobility challenges [1]. For the future of Dutch cities, strategies are developed to ensure that the quality of life and accessibility will be maintained in the years to come. These strategies are aimed at reducing driving and parked cars, and improving clean and active travel [2, 3]. Mobility hubs are among the key elements of these strategies [2, 3, 4, 5, 6]. Mobility hubs are locations where shared mobility modes can be offered.

Despite the growing body of research dedicated to mobility hubs, the actual impact of mobility hubs on car use and car ownership is unknown [7, 8, 9]. The acceptance and use of mobility hubs as a substitute for the private car is still unexplored [7, 8, 9]. Hence, it is unknown to what extent mobility hubs will change car use and car ownership. Therefore, insight needs to be gained into the decision-making process of Dutch car owners regarding the services offered in mobility hubs. That is what this research will focus on.

While this research is academically relevant, it is also relevant from a social point of view. The outcome of this research is relevant and useful for transport engineering companies. The potential of mobility hubs to replace the private cars is in line with the desire of Dutch municipalities to reduce car use and car ownership of residents in these cities. This research aims to explore and measure the factors that influence people's willingness to use shared mobility alternatives offered in mobility hubs for trips and the willingness to give up the least used car.

This research focuses on mobility hubs that exclusively offer electric shared mobility alternatives, since electric shared mobility is currently the standard in the Netherlands and is expected to become even more common in the coming years [10]. It is assumed that in mobility hubs shared e-cars, e-mopeds and e-bikes are offered given their current presence in the Dutch transport system. Shared mobility services are mainly and only effective in replacing the least used car, therefore this research focuses on the least used private car [9, 11]. Due to the interest from municipalities and the problems related to private cars, this research focuses on all types of residential environments in the Randstad. This concerns city centres, suburban areas and rural areas [12].

To examine the effects of mobility hubs on car use and car ownership, two stated choice experiments are designed. In the first experiment, respondents are asked for commuting trips to choose the most preferred alternative. While in the second experiment, respondents are asked for all trips to choose between the private car and mobility hubs and therefore to give up the private car. The experiments are conducted through an online survey via the software package Qualtrics, which allowed for a personalised and user-friendly survey. Based on the data from the respondents and the experiments, multinomial logit models are used to estimate the parameters. The parameters and results of the choice models provide insight into the impact of the trip time components, travel cost components and the car owner's personal and living environment characteristics when shared mobility services offered in mobility hubs.

This paper discusses the research approach and the survey, the data collection and the sample, the results of the models, the application and effects of mobility hubs on existing residential areas in the Netherlands. The final section provides conclusions, and recommendations for further research.

2 Research approach and survey

The focus of this research is on the trade-offs that car owners make in the choice between the car and shared mobility services for commuting trips and the trade-offs in the choice to give up the private car and thus use shared mobility services for all trips. The first experiment is called the short-term mode choice experiment, while the second experiment is called the long-term mode choice experiment. The first experiment is only completed by respondents using the private car for commuting trips, whereas the second experiment is completed by all respondents.

The alternatives in the stated choice experiments reflect the alternatives for these situations, i.e. the private car and shared mobility services. The private car alternative represents the private

Table 1: The three choice sets for the two stated choice experiments.

Alternatives	Short-term mode choice experiment 7.5 km or 22.5 km	45 or 75 km	Long-term mode choice experiment 500, 1500 or 2500 km
Private car	•	•	•
Shared e-car	•	•	
Shared e-moped	•		
Shared e-bike	•		
Mobility hub			•

car of the respondents in the experiments. In the short-term mode choice experiment, a choice could be made between the private car and the shared modes, while in the long-term mode choice experiment, a choice could be made between the private car or the mobility hub consisting of the three shared mobility modes. The choice sets for the two stated choice experiments are shown in table 1.

Based on the distance to work and the total monthly travel distance of the respondents, the respondents are assigned to experiments that resemble their real situation in both the short and long-term mode choice experiment. For the short-term mode choice experiment there are four distance category experiments i.e. 7.5, 22.5, 45 and 75 kilometres, whereas for the long-term mode choice experiment there are three monthly distance category experiments i.e. 500, 1500 and 2500 kilometres. This makes the experiments more personalised, allowing respondents to better understand the situations in the experiments.

The mode choice factors are categorised into three groups, all of which are included in the survey. The first group are the trip characteristics, see table 2. Trip time consists of access time, travel time and egress time attributes. The travel times for both the private car and the shared mobility alternatives are fixed and mode dependent. The access time and egress time attributes vary over three levels. The different trip time components of the different alternatives are perceived differently, therefore the attributes are alternative specific attributes [13]. The travel cost consists of monthly costs and operating cost attributes. The travel cost components for the private car are fixed. The values are based on the costs of an average car in the Netherlands [14]. The travel costs components for the shared mobility services are based on the costs of the use of shared mobility services offered in a mobility hub in the Netherlands [15]. The monthly costs and operating cost attributes for shared mobility vary across three levels. The travel costs attributes for the shared mobility alternatives are alternative specific attributes as well. The last factor is the mode preference factor. As it is unknown as to how car owners would use the shared mobility services as a substitute for the private car, a usage scenario attribute is added that varies over four levels, see table 2. The meaning of the four levels can be found in table 3.

The second group are the traveler characteristics related to the car owner. These are obtained through questions in the survey. Next to the standard socio-demographic questions, familiarity with shared mobility services and experience with these services are also asked.

The third and last group are the spatial characteristics related to the living environment of the car owner. These factors enable insight into the differences in trade-offs of people who live in a city centre, suburban area or rural area.

Table 2: Attributes together with the associated attribute level values for the two stated choice experiments.

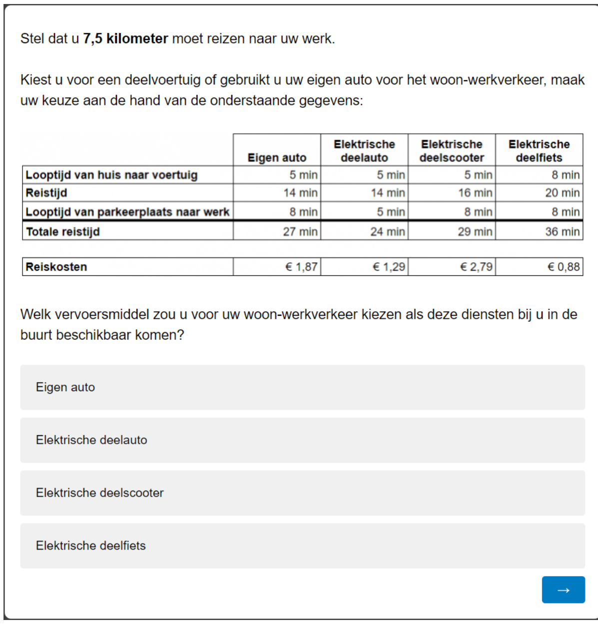
Alternative	Category	Attribute		Level 0	1	2	3
Private car	Trip time	Access time [min]		2	5	8	
		Travel time [min]			Fixed		
		Egress time [min]		2	5	8	
	Travel costs	Monthly costs [€]			Fixed		
		Operating costs [€/km]			Fixed		
Shared mobility	Trip time	Access time [min]		2	5	8	
		Travel time [min]			Fixed		
		Egress time [min]		2	5	8	
	Travel costs	Monthly costs [€]		10	30	50	
		Operating costs [€/km]	Shared e-car	0.058	0.175	0.292	
			Shared e-moped	0.075	0.226	0.377	
			Shared e-bike	0.039	0.118	0.197	
	Mode preference	Usage scenario		Full	High	Mid	Low

Table 3: Attribute level explanation for the usage scenario attribute.

Attribute level	Description
Full	100% of the trips with a shared e-car
High	85% of the trips with a shared e-car, 10% with a shared e-moped, and 5% with a shared e-bike
Mid	70% of the trips with a shared e-car, 20% with a shared e-moped, and 10% with a shared e-bike
Low	55% of the trips with a shared e-car, 30% with a shared e-moped, and 15% with a shared e-bike

The hypothetical scenarios in the experiments might cause a bias in the answers. To avoid the bias as much as possible, several measures are taken. According to the respondents' characteristics, the respondents are assigned to the appropriate experiments for both the short-term and long-term mode choice experiment, see table 1. The alternatives and the corresponding attributes are explained prior to the experiments, whereby the attribute levels are realistic and therefore easy to understand for the respondents. Finally, several pilot surveys were conducted to ensure that the survey was completely clear and without errors.

The experimental designs are constructed using the software package Ngene. For the short-term mode choice experiments, there is an orthogonal design with 36 choice situations per experiment for the distances of 7.5 and 22.5 kilometres, whereas there are twelve choice situations for the distances of 45 and 75 kilometres. For the first two distances, the choice situations are divided into six blocks of six choice situations each, and for the last two distances into three blocks of four choice situations each. For the long-term mode choice experiments there is an orthogonal design with 36 choice situations per experiment. The choice situations are divided into six blocks of six choice situations. In this way, respondents have to make six, ten or twelve choices in the survey. Examples of the short-term and long-term mode choice experiments can be seen in figures 1 and 2 respectively.



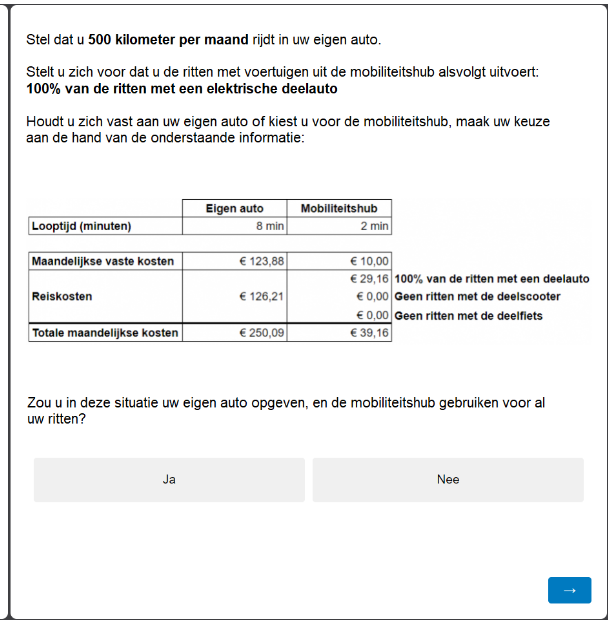


Figure 1: Example of a choice situation for the short-term mode choice experiment.

Figure 2: Example of a choice situation for the long-term mode choice experiment.

3 Data collection and sample

To participate in the survey, respondents have to own a private car or be willing to buy a car within a year. Respondents with a lease car are excluded from this survey. In order to recruit a good mix of respondents from the Randstad region for the survey, various strategies are implemented. Respondents are approached through posts on various social media platforms, flyers with a QR code are handed out on the street, the survey are published on SurveyCircle and is shared amongst friends and family.

The survey was online between 1 October 2020 and 19 November 2020. A total of 773 respondents started the survey, of which 709 eventually completed it. 533 respondents started the survey via the anonymous link, and 176 via the QR code on the flyer. Finally, the respondents that did not have a car, had a lease car or were not willing to buy a car within 12 months had to be removed from the sample. As a result, the sample used for this research contains 574 respondents. 495 respondents participated in the short-term mode choice experiment, compared to all 574 respondents of the whole survey and of the long-term mode choice experiment. The number of respondents that participated in the different experiments can be found in table 4.

Table 5 presents the socio-demographic characteristics of the survey respondents. The sample of respondents for this research consists mainly of inhabitants of South Holland, North Holland and Utrecht. Sufficient respondents were found in the focus areas of this research, namely the city centres, suburbs and rural areas. The respondents were mainly young people who are highly educated and have a high income.

Almost half of the respondents had ever used a shared bike, while almost 16% had used a shared car, which is the least. Respondents were also most familiar with the shared car, nearly 2% had never heard of it, whereas almost 8% had never heard of the shared moped. Despite that, the shared moped was rated best, followed by the shared car and the shared bike was rated worst.

Table 4: The absolute number and percentage of respondents that participated in the short-term and long-term mode choice experiments.

Stated choice experiment	Distance	Respondents
Short-term mode choice experiment	7.5 km	153 (30.9%)
	22.5 km	121 (24.4%)
	45 km	131 (26.5%)
	75 km	90 (18.2%)
Long term mode choice experiment	500 km	253 (44.1%)
	1500 km	190 (33.1%)
	2500 km	131 (22.8%)

Table 5: Descriptive statistics of the sample.

Variable	Category	Percentage in sample
Gender	Female	48.6%
	Male	51.0%
	Different	0.3%
Age	18 - 35	28.2%
	36 - 65	63.4%
	66+	8.4%
Education	Low	1.4%
	Medium	12.4%
	High	86.2%
Income level	0 - 36000	20.4%
	36000 - 72000	47.9%
	72000 or more	27.7%
	Unknown	4.0%
Living environment	City centre	20.0%
	Suburban area	39.9%
	Rural area	40.1%

4 Results

This chapter discusses the results of the models for the two stated choice experiments.

For both stated choice experiments, two models were used and the models were finally estimated using the software package BisonBiogeme [16].

First, a base multinomial logit model was estimated for each distance for both the short- and long-term mode choice experiment. The base MNL model consisted of the main parameters that

Table 6: Performance of the estimated models.

Experiment	Distance	Model	Parameters	Final LL	Adjusted rho-square
Short-term mode choice experiment	7.5 km	Base MNL	14	-842.546	0.327
		Extended MNL	26	-812.057	0.341
	22.5 km	Base MNL	14	-455.504	0.533
		Extended MNL	23	-439.594	0.540
	45 km	Base MNL	6	-214.934	0.391
		Extended MNL	10	-212.946	0.394
	75 km	Base MNL	6	-134.977	0.433
		Extended MNL	10	-131.770	0.439
Long-term mode choice experiment	500 km	Base MNL	10	-901.540	0.133
		Extended MNL	14	-885.003	0.145
	1500 km	Base MNL	10	-623.884	0.197
		Extended MNL	14	-617.820	0.200
	2500 km	Base MNL	10	-376.742	0.284
		Extended MNL	14	-369.134	0.290

were attributes in the stated choice experiment. Furthermore, each alternative had an alternative specific constant, but for one alternative the ASC was set to zero, which is the reference alternative.

For a more accurate estimate of how Randstad residents from defined residential areas respond to shared mobility and whether these respondents are willing to give up their least used private car, variables were added. Specifically, these were dummy variables. Dummy variables for living environment and the number of cars in a household were added to the base MNL model. The result was the extended multinomial logit model.

For the assessment of the performance of the models, two methods were used, see table 6. First, the Likelihood Ratio Test Statistic, for all distance categories of both experiments the extended MNL models performed better. Moreover, the values of the adjusted rho-squared also increased from the base MNL models to the extended MNL models. There was an improvement in the explanatory power from base MNL to extended MNL.

The final parameter estimates provided insight into the effects of the attributes and socio-demographic characteristics on the choice of respondents. First, the short-term model is discussed, followed by the long-term model. For the interpretation of the models, only trends in which the difference between two variables found are significant at a confidence interval of at least 90% or stronger are identified. Moreover, the interpretation between the differences of two or more variables is based on the assumption that the trends are only valid if the other factors are equal.

In table 7, the estimated parameter values are listed for the short-term model. The table shows the significance levels of the parameters for the confidence intervals of 99%, 95% and 90%. On these confidence intervals, the parameters have the expected sign. The results of the discrete choice models for the short-term mode choice experiment provided interesting new insights.

A positive preference for the use of the shared e-car over the private car for commuting trips was found. However, the decision to opt for a shared e-car for commuting trips depends on various factors.

For short distances of 7.5 kilometres to work, respondents living in households with one or two cars are more willing to use a shared mobility alternative than respondents living in households with three cars or more. Besides, residents of a city centre (and suburban area) are more likely to use a shared e-car than residents of a rural area for the same short distances of 7.5 and 22.5 kilometer to work.

The trip costs for the commuting trip are important. The sensitivity of the trip costs for the shared e-car is higher than that of the shared e-moped and the shared e-bike, implying that for an equal increase in trip costs, the shared e-car generates higher disutilities than the shared e-moped and shared e-bike.

Interesting insights were also obtained for walking times. Respondents assess the access time and egress time for a trip with an alternative almost the same. A trend, however, can be discerned between the various alternatives. For distances of 7.5 and 22.5 kilometres to work, the sensitivity to walking time seems to be highest for the shared e-bike, followed by the shared e-moped. While the results showed that the walking times of the private car are almost equally sensitive to the walking times of the shared e-car. For long distances of 45 and 75 kilometres to work, the respondents seemed to assess the walking times for the private car and the shared e-car the same.

In table 8, the estimated parameter values are listed for the long-term model. The table shows the significance levels of the parameters for the confidence intervals of 99%, 95% and 90%. On these confidence intervals, the parameters have the expected sign. A monthly travel distance of 500 kilometres is considered low car use, while 1500 kilometres per month is considered moderate car use, and high car use is 2500 kilometres per month. The results for the long-term mode choice experiment also provided interesting new insights.

There appeared to be a positive preference for the mobility hub over the private car, however, the decision to give up the private car depends on several factors.

Respondents who live in a household with one or two cars are more likely to give up the least used car than respondents who live in a household with three cars or more for a low monthly use of the private car. Respondents with low to moderate private car use and living in a city centre are more likely to give up the least used private car than respondents living in a rural area.

For the same monthly use, the model showed that the sensitivity to an increase in walking time from home to a mobility hub is greater than that of to the private car, implying that for an equal increase in walking time, the mobility hub generates higher disutilities than the private car.

Respondents are sensitive to the monthly costs that have to be paid for the use of the mobility hub. Sensitivity to operating costs is highest for the shared e-car, and thus higher than for the shared e-moped and shared e-bike. This may be related to the preference of car owners to use the shared e-car.

Car owners who are willing to give up the least used private car and start using mobility hubs have a preference for full use of the shared e-car, and little preference for using the shared e-moped and shared e-bike.

Table 7: Parameter estimations of extended MNL models for short-term mode choice experiment. *** indicates significant on a 99% confidence level, ** indicates significant on a 95% confidence level, * indicates significant on a 90% confidence level.

	7.5 km					22.5 km					45 km					75 km				
Name	Value	Robust Std err	Robust t-test	p-value		Value	Robust Std err	Robust t-test	p-value		Value	Robust Std err	Robust t-test	p-value		Value	Robust Std err	Robust t-test	p-value	
Private car																				
(Reference Alternative)																				
BETA_CAR_AD	-0.24	0.0358	-6.69	0	***	-0.109	0.0382	-2.85	0	***	-0.205	0.0476	-4.3	0	***	-0.113	0.0662	-1.71	0.09	*
BETA_CAR_ED	-0.185	0.0354	-5.23	0	***	-0.165	0.0398	-4.15	0	***	-0.158	0.0706	-2.24	0.03	**	-0.261	0.107	-2.44	0.01	**
E-car																				
ASC_ECAR	0.658	0.503	1.31	0.19		2.11	0.478	4.41	0	***	3.74	0.81	4.62	0	***	4.41	1.15	3.82	0	***
BETA_ECAR_AD	-0.0849	0.0373	-2.28	0.02	**	-0.0829	0.0401	-2.07	0.04	**	-0.153	0.0465	-3.28	0	***	-0.155	0.0631	-2.46	0.01	**
BETA_ECAR_ED	-0.168	0.0371	-4.52	0	***	-0.0743	0.0396	-1.88	0.06	*	-0.209	0.0494	-4.22	0	***	-0.169	0.0694	-2.43	0.01	**
BETA_ECAR_TC	-17.8	1.14	-15.64	0	***	-16.6	1.19	-14.01	0	***	-19.9	1.88	-10.55	0	***	-23.4	2.95	-7.94	0	***
BETA_ECAR_CARS_ONE	0.979	0.365	2.68	0.01	***	-0.151	0.234	-0.65	0.52		-0.123	0.54	-0.23	0.82		0.612	0.575	1.06	0.29	
BETA_ECAR_CARS_TWO	1.38	0.342	4.04	0	***						-0.101	0.507	-0.2	0.84		0.933	0.508	1.84	0.07	*
BETA_ECAR_LIVING_CENTER	0.832	0.295	2.82	0	***	0.631	0.259	2.43	0.01	**	0.247	0.343	0.72	0.47		-0.277	0.468	-0.59	0.55	
BETA_ECAR_LIVING_SUBURB	0.406	0.234	1.74	0.08	*	0.708	0.242	2.92	0	***	0.533	0.266	2.01	0.04	**	-0.407	0.342	-1.19	0.23	
E-moped																				
ASC_EMOPED	-0.565	0.672	-0.84	0.4		-2.35	1.11	-2.11	0.03	**										
BETA_EMOPED_AD	-0.259	0.049	-5.28	0	***	-0.0644	0.0901	-0.72	0.47											
BETA_EMOPED_ED	-0.194	0.0504	-3.84	0	***	-0.24	0.115	-2.09	0.04	**										
BETA_EMOPED_TC	-12.3	1.41	-8.73	0	***	-7.63	2.87	-2.66	0.01	***										
BETA_EMOPED_CARS_ONE	1.84	0.5	3.69	0	***	0.557	0.436	1.28	0.2											
BETA_EMOPED_CARS_TWO	1.68	0.471	3.57	0	***															
BETA_EMOPED_LIVING_CENTER	0.585	0.363	1.61	0.11		1.54	0.574	2.68	0.01	***										
BETA_EMOPED_LIVING_SUBURB	0.331	0.288	1.15	0.25		-0.461	0.884	-0.52	0.6											
E-bike																				
ASC_EBIKE	0.384	0.53	0.72	0.47		-0.501	2.01	-0.25	0.8											
BETA_EBIKE_AD	-0.337	0.0473	-7.12	0	***	-0.383	0.17	-2.25	0.02	**										
BETA_EBIKE_ED	-0.272	0.0462	-5.88	0	***	-0.671	0.243	-2.76	0.01	***										
BETA_EBIKE_TC	-14	1.75	-8	0	***	-6.17	6.15	-1	0.32											
BETA_EBIKE_CARS_ONE	0.815	0.393	2.08	0.04	**	-1.87	1.04	-1.81	0.07	*										
BETA_EBIKE_CARS_TWO	1.34	0.354	3.78	0	***															
BETA_EBIKE_LIVING_CENTER	0.0905	0.348	0.26	0.8		1.6	0.855	1.87	0.06	*										
BETA_EBIKE_LIVING_SUBURB	0.244	0.251	0.97	0.33		0.803	0.894	0.9	0.37											

Table 8: Parameter estimations of extended MNL models for long-term mode choice experiment. *** indicates significant on a 99% confidence level, ** indicates significant on a 95% confidence level, * indicates significant on a 90% confidence level.

	500 km					1500 km					2500 km				
Name	Value	Robust Std err	Robust t-test	p-value		Value	Robust Std err	Robust t-test	p-value		Value	Robust Std err	Robust t-test	p-value	
Private car															
ASC_CAR	-1.15	0.378	-3.04	0	***	-2.9	0.502	-5.77	0	***	-3.26	0.657	-4.96	0	***
BETA_CAR_AD	-0.154	0.0247	-6.22	0	***	-0.198	0.0328	-6.06	0	***	-0.302	0.0437	-6.91	0	***
BETA_CAR_CARS_ONE	-1.22	0.242	-5.02	0	***	-0.248	0.272	-0.91	0.36		-0.684	0.355	-1.92	0.05	*
BETA_CAR_CARS_TWO	-1.08	0.231	-4.67	0	***	-0.359	0.25	-1.44	0.15		-0.944	0.309	-3.06	0	***
BETA_CAR_LIVING_CENTER	-0.363	0.152	-2.39	0.02	**	-0.561	0.196	-2.87	0	***	-0.123	0.271	-0.45	0.65	
BETA_CAR_LIVING_SUBURB	-0.072	0.133	-0.54	0.59		-0.369	0.154	-2.39	0.02	**	-0.361	0.202	-1.79	0.07	*
E-hub															
(Reference Alternative)															
BETA_EHUB_AD	-0.205	0.0256	-8	0	***	-0.284	0.0345	-8.21	0	***	-0.289	0.0459	-6.29	0	***
BETA_EHUB_SF	-0.0151	0.00369	-4.09	0	***	-0.0134	0.00473	-2.82	0	***	-0.0141	0.00659	-2.14	0.03	**
BETA_EHUB_SCENARIO_HI	-0.491	0.171	-2.87	0	***	-0.471	0.22	-2.14	0.03	**	-0.424	0.285	-1.49	0.14	
BETA_EHUB_SCENARIO_MED	-1.04	0.17	-6.15	0	***	-1.24	0.22	-5.66	0	***	-1.59	0.272	-5.84	0	***
BETA_EHUB_SCENARIO_LOW	-2.04	0.18	-11.35	0	***	-2.2	0.239	-9.19	0	***	-2.6	0.294	-8.87	0	***
BETA_EHUB_TC_ECAR	-2.99	0.643	-4.64	0	***	-7.34	0.88	-8.34	0	***	-11.7	1.2	-9.78	0	***
BETA_EHUB_TC_EMOPED	-0.744	0.479	-1.55	0.12		-2	0.642	-3.12	0	***	-2.36	0.929	-2.54	0.01	**
BETA_EHUB_TC_EBIKE	0.095	0.892	0.11	0.92		1.01	1.1	0.92	0.36		-1.13	1.49	-0.76	0.45	

5 Effects of mobility hubs in residential areas

This section discusses the results of the effect of mobility hubs on car use and ownership for different residential areas.

Considering the interest of municipalities in mobility hubs and the problems regarding private cars, this research focused on all types of living environments in the Randstad. These included a city centre, a suburb and a rural area [12].

In this research it was assumed that a city centre is a typical city centre for a city in the Randstad, with a car ownership rate of 0.5 cars per household. Based on discussions with shared mobility consultants from Sweco, it emerged that for a city centre, a maximum walking time of 5 minutes was appropriate and acceptable.

For a suburban area, it was assumed that it borders a city centre of a city in the Randstad, with a car ownership rate of 1.0 cars per household. Based on the same discussions with Sweco consultants, it turned out that for a suburban area a maximum walking time of 10 minutes was appropriate.

Lastly, it was assumed that a rural area is a non-city area within the Randstad region, with a car ownership rate of 1.5 cars per household. A maximum walking time of 10 minutes to a mobility hub is appropriate for a rural area, as emerged from the same discussions with Sweco's consultants.

In order to obtain useful results regarding the effect of mobility hubs on car use and car ownership, it is important to have realistic scenarios for the three areas of interest. Therefore, different mobility hub grid plans are proposed and considered, realistic values are established as input and finally strategies of Dutch municipalities are explored.

This research covered three types of mobility hub grid plans. The first type of grid plan consisted of mobility hubs with a maximum walking time of 2 minutes from home to a mobility hub, which creates a high density hub grid plan. The second type of grid plan is formed by mobility hubs with a maximum walking time of 5 minutes, in this research this is called the intermediate density hub grid plan. Finally, a low density hub grid plan is composed of mobility hubs with a maximum walking time of 10 minutes in a built-up area. For the design of these grid plans, it is assumed that a walking time of 2,5 and 10 minutes equals 132,330 and 660 metres respectively.

In an area with a perfect distribution of mobility hubs, 29 mobility hubs per square kilometre must be built for a high density hub grid plan. Five mobility hubs per square kilometre are needed for an intermediate density hub grid plan. A low density hub grid plan requires only one mobility hub per square kilometre.

In a perfectly distributed grid of mobility hubs, there are households that live closer to a mobility hub than the maximum distance indicated. This could lead to an underestimation of the willingness of people to use shared mobility services. Therefore, for the three hub grid plans the percentage of the household that lives at a shorter walking time to a mobility hub than the maximum distance was estimated, as presented in table 9.

In order to estimate the effects of the mobility hubs and the strategies, realistic values must be used as input for the variables in the models. The inputs were based on the results of this research, realistic values in the Netherlands, and assumptions.

Table 9: Overview of the share of households at a maximum walking times to a mobility hub for the different hub grid plans.

Walking time	High density	Intermediate density	Low density
1 minute	39.3%	6.3%	1.6%
2 minutes	60.7%	18.8%	4.7%
3 minutes		31.4%	7.9%
5 minutes		43.5%	25.1%
7 minutes			37.7%
10 minutes			23.0%

For the private car, it was assumed that the access time from home to the private car was 2 minutes, based on the average walking times of the respondents in the survey. Although the egress time from parking place to work strongly depends on the location, an average of 4 minutes was assumed.

The input of the access time depends on the mobility hub grid plan in the scenario. Table 9 was used as input to the models to give a more accurate estimate of the walking times of the residents in the focus areas. For the sake of simplicity, the same input value was used for the egress time as the input value of the access time for the short-term model. The same mobility hub grid plan was assumed on the activity side as on the home side.

In the Netherlands, there are several shared mobility service providers. Based on these providers, realistic operating costs for the shared e-car, e-moped and e-bike were determined. The operating costs per kilometre travelled for the three shared mobility alternatives can be found in table 11. Based on the only mobility hub operator in the Netherlands, the monthly costs were assumed to be 30 euros.

Full use of the shared e-car was most preferred by car owners as a substitute for the private car. Therefore, it was assumed as input for the long-term model that car owners would make full use of the shared e-car in the longer term.

Municipalities in the Netherlands want not only to facilitate mobility hubs, but also to further stimulate their use. The two strategies considered in this research were the construction of more mobility hubs and the reduction of operating costs for the use of shared mobility services.

Based on the discussions with shared mobility experts, an intermediate density hub grid plan would fit a city centre, while a low density hub grid plan would fit both a suburban and a rural area. Increasing the number of mobility hubs in a neighbourhood is the first strategy considered. The result is a higher density of mobility hubs, which reduces the walking times from a household to a mobility hub. For each of the focus areas, two types of mobility hub grid plans were considered, one that suits the type of neighbourhood and one with a higher mobility hub density, which are presented in table 10.

The second strategy considered is the reduction of operating costs of the shared mobility services. The original operating costs are reduced by 20% and 40% to evaluate the effect on the willingness of residents of the focus areas to use shared mobility services. The original operating costs and the two reduced operating costs per kilometre travelled for the shared mobility alternatives are presented in table 11.

Table 10: The focus areas with the associated hub grid plans

Focus area	Low density	Intermediate density	High density
City centre		•	•
Suburban area	•	•	
Rural area	•	•	

Table 11: The operating costs for the three shared mobility options in this research.

Alternative	Original operating costs	20% reduction of original operating costs	40% reduction of original operating costs
Shared e-car	€ 0.268	€ 0.215	€ 0.161
Shared e-moped	€ 0.489	€ 0.392	€ 0.294
Shared e-bike	€ 0.123	€ 0.098	€ 0.074

The results for the three focus areas with the different mobility hub grid plans and the pricing strategies showed that there is an effect on the use of the least used private car in the short term. The effect of mobility hubs with the strategies on the reduced use of the least private car is shown in table 12. The willingness to use shared mobility services is slightly higher in the city centre and suburban area than in the rural area. Therefore, the reduction in private car use in the city centre and suburban area is slightly greater than in the rural area. Moreover, a higher mobility hub density and a reduction of the operating costs of the shared mobility services lead to a greater reduction in the least private car use.

The preference for using the shared e-car as an alternative to the private car is high for commuting trips. For commuting trips, there is some preference for using the shared e-bike, and hardly any for using the shared e-moped. Since the use of the shared e-car is attractive to car owners, mobility hubs will not lead to a large decrease in car trips, as shown in table 13. The table shows the share of the least used private car and the shared e-car together for commuting trips. The share of car movements is smaller as the density of the mobility hubs increases. In that case, car owners are more willing to opt for a shared e-moped or a shared e-bike.

Table 12: Overview of the reduction of the least used private car use for the different focus areas for the different strategies.

Focus area	Mobility hub grid plan	Original operating costs	20% reduction of original operating costs	40% reduction of original operating costs
City centre	High density	36.2%	56.1%	75.5%
	Intermediate density	22.6%	40.2%	62.0%
Suburban area	Intermediate density	23.1%	40.6%	62.0%
	Low density	11.7%	23.1%	41.5%
Rural area	Intermediate density	21.2%	36.7%	56.3%
	Low density	10.3%	20.4%	36.7%

Table 13: Overview of the share of trips using the least used private car and shared e-car for the different focus areas for the different strategies.

Focus area	Mobility hub grid plan	Original operating costs	20% reduction of original operating costs	40% reduction of original operating costs
City centre	High density	85.0%	83.9%	84.4%
	Intermediate density	92.5%	91.4%	90.9%
Suburban area	Intermediate density	92.2%	90.8%	90.1%
	Low density	97.1%	96.4%	95.9%
Rural area	Intermediate density	91.7%	90.3%	89.5%
	Low density	97.0%	96.3%	95.7%

The result for the three focus areas with the different mobility hub grid plans and the pricing strategies showed that there is an effect on car ownership in the long term at household level. The effect of mobility hubs on giving up the least used private car is shown in table 14. For the same mobility hub grid plan and the same operating costs, the willingness to give up the least used car is greatest for residents of the city centre, followed by those in the suburban area and least in the rural area. Moreover, a higher mobility hub density and a reduction in the operating costs of the shared mobility services lead to a greater reduction in car ownership in the focus areas.

The results on the willingness to give up the least used private car were used to determine the effect on car ownership at neighbourhood level. At neighbourhood level, the effects on car ownership for the three focus areas are shown in table 15. The effect on the number of cars per household in the neighbourhood with the same mobility hub grid plan and the same operating costs is the largest in the city centre, followed by the suburban area and the smallest in the rural area. Despite the fact that in a city centre the smallest number of cars per household is found, the percentage decrease is still the strongest.

For the focus areas with the same mobility hub grid plan and the same operating costs, the models showed that in the long term the willingness to give up the least used car was greater than the willingness to use a shared mobility alternative for commuting trips. In the stated choice experiments, there was full insight into the trip costs and total monthly costs for both the private car

Table 14: Overview of the share of households that would give up the least used private car for the different focus areas for the different strategies.

Focus area	Mobility hub grid plan	Original operating costs	20% reduction of original operating costs	40% reduction of original operating costs
City centre	High density	61.0%	71.6%	80.9%
	Intermediate density	50.3%	61.0%	71.8%
Suburban area	Intermediate density	46.9%	58.1%	69.2%
	Low density	32.1%	41.2%	52.0%
Rural area	Intermediate density	42.1%	52.9%	64.5%
	Low density	28.4%	36.7%	47.1%

Table 15: Overview of the effect on the reduction of car ownership at neighbourhood level for the different focus areas for the different strategies.

Focus area	Mobility hub grid plan	Original operating costs	20% reduction of original operating costs	40% reduction of original operating costs
City centre	High density	61.0%	71.6%	80.9%
	Intermediate density	50.3%	61.0%	71.8%
Suburban area	Intermediate density	46.9%	58.1%	69.2%
	Low density	32.1%	41.2%	52.0%
Rural area	Intermediate density	28.0%	35.3%	43.0%
	Low density	18.9%	24.5%	31.4%

and the shared mobility services. This allowed respondents a clear insight into the costs that could be saved per trip and per month. The financial decision to give up the private car can therefore be an incentive. Moreover, car owners pay a fixed monthly fee for having a private car, even if they do not use it. The decision to use a shared mobility service may therefore be a disincentive.

In both the short and long term, the density of mobility hubs in the built-up area is an important factor. A higher mobility hub density leads to an increase in the willingness to use shared mobility services and the willingness to give up the private car. A higher mobility hub density also leads to an increase in the preference for the shared e-car and e-bike. A transition from car movements to more active travel movements, such as bicycle movements, can be stimulated by a higher mobility hub density.

The operating costs of shared mobility services are also important factors for their use in the short and long term. Reducing the operating costs can make the use of shared mobility services for work-related trips more preferred and increase the willingness to give up the private car. However, reduction of the original operating costs of the three shared mobility alternatives only increases the preference for the use of the shared e-car. The preference for the use of shared e-bike and e-moped can increase either when the operating costs for both are reduced or when the operating costs of the shared e-car are increased.

All in all, the models showed that under defined conditions mobility hubs can actually have an effect on car use and car ownership. For a transition to less car use and car ownership, a dense network of mobility hubs is desirable. For a city centre a high density hub grid is advisable, and for both a suburban and rural area an intermediate density hub grid plan is advisable. In reality, for the city of Delft a mobility hub configuration for the entire city could resemble as shown in figure 3. In the city centre there is a high density of mobility hubs, while in the rest of the city there is an intermediate density of mobility hubs. The yellow areas around the dots, representing the mobility hub, have a 1-minute walking time to mobility hubs. The blue areas have a 2-minute walking time to mobility hubs, while the pink area is a 3-minute walking time to mobility hubs. The rest of the areas have a 5-minute walking time to mobility hubs. In this figure it is clearly visible that a high density hub grid plan is extreme, whereas an intermediate density hub grid plan is more conceivable to realise.

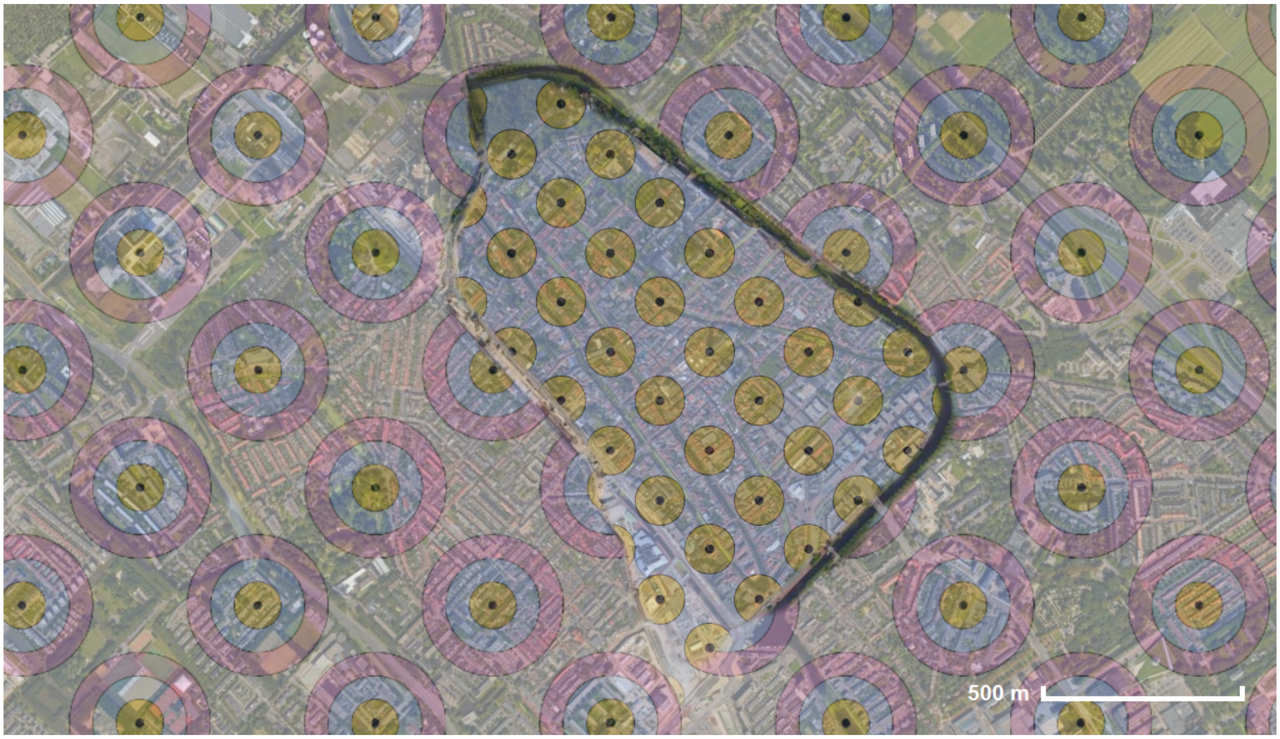


Figure 3: Visualisation of the city of Delft with high and intermediate density hub grid plans.

6 Conclusion and recommendations

This research aimed at exploring and measuring the effects of mobility hubs on car use and car ownership. Two stated choice experiments were designed and conducted. Extended multinomial logit models were used to estimate the factors on mode preferences in the short and long term. The factors affecting mode choice classified into traveller characteristics, trip characteristics and living environment characteristics were assessed separately for the short and long term.

A positive preference for the use of the shared e-car over the private car for commuting trips was found. However, the decision to opt for a shared e-car for commuting trips depends on various factors. Moreover, residents of a city centre (and suburban area) are more likely to use a shared e-car than residents of a rural area for short distances of 7.5 and 22.5 kilometer to work. The sensitivity for the trip costs is higher for the shared e-car than for the shared e-moped and e-bike. For distances of 7.5 and 22.5 kilometres to work, sensitivity to walking times is greatest for the shared e-bike, followed by the shared e-moped. While the results showed that the walking times of the private car are almost equally sensitive to the walking times of the shared e-car. For distances of 45 and 75 kilometres to work, the sensitivity to walking times for the private car and the shared e-car is almost equal.

There appeared to be a positive preference for the mobility hub over the private car, however, the decision to give up the private car depends on several factors. Respondents with a low monthly car use and who live in a household with one or two cars are more likely to give up the least used car than respondents who live in a household with three cars or more. Moreover, respondents with low to moderate private car use and who live in a city centre are more likely to give up the private car than respondents who live in a rural area. The sensitivity to walking times from household to mobility hub is higher than to a private car. The sensitivity to operating costs of the shared e-car is higher than those of the shared e-moped and e-bike. Car owners who are willing to give up the least used car prefer full use of the shared e-car as a substitute for the private car.

The impact of mobility hubs on car use and car ownership was analysed for three focus areas. These three areas were a city centre, a suburban area and a rural area in the Randstad in the Netherlands. The willingness to use shared mobility services for commuting trips is slightly greater in a city centre and suburban area than in a rural area. Therefore, the reduction in private car use in the city centre and suburban area is slightly greater than in the rural area. Since the preference for the use of the shared e-car is high, mobility hubs do not greatly reduce the number of car movements. The willingness to give up the least used car is highest for residents of the city centre, followed by those of the suburban area and is lowest in those of the rural area. The effects on the number of cars per household in the district are greatest in the city centre, followed by the suburban area and by far the least in the rural area. In both the short term and the long term, the density of mobility hubs is an important factor. A higher mobility hub density increases the willingness to use shared mobility services and also increases the willingness to give up the least used private car. Moreover, the operating costs of the shared mobility services are also important factors. The reduction of operating costs may increase the willingness to use shared mobility services for commuting trips, and also increases the willingness to give up the least used private car.

This research provided some insights into the decision-making process regarding the acceptance of mobility hubs. In follow-up studies other attributes can be included, such as availability of shared mobility services and presence of facilities in mobility hubs. In the coming years, data will be available on the use of shared mobility modes in mobility hubs, which will provide more realistic and better insights into the actual effects of mobility hubs.

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