Modal shift strategies from car to public transport via shared bicycle integration

A case study on suburban commuting in South Holland

Master Thesis

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provincie Zuid-Holland

Modal shift strategies from car to public transport via shared bicycle integration

A case study on suburban commuting in South Holland

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Cover: OV-Fiets used by commuters in Utrecht (Fiets123, 2015)

Preface

This thesis marks the end of my 5-plus years here at the TU Delft. My time in Delft was a journey that has been filled with both personal and professional growth. One I can look back on with a lot of pride, from overcoming almost a full bachelor of online study at home due to COVID-19, to professionalising different programs, subjects, and professional skills. The latter comes together in this thesis, which marks the last hurdle before finally being able to call myself a Civil Engineer. This thesis itself has been its own adventure. From struggling with acquiring every respondent, while staying confident in the process and my knowledge and skills, to this report that I can present with pride.

A big thank you to Serge for chairing my thesis committee, and to Niels for critically assessing my work, reassuring my decisions, helping me with decision-making, and taking the time to supervise this project. I want to thank Dorine for helping me with the more technical part of my research and taking the time for me even in the weeks when I bombarded you with my modelling questions. Despite not being my official supervisor, I want to thank Nejc for always being eager to answer my questions and taking the time to help me reach the end goal of my thesis. I would like to thank Ronald for the assistance in the process from Provincie Zuid-Holland. Your extensive experience and knowledge of bicycle sharing and its application helped my thesis not only be scientifically complete but also be of great use to the province to elevate the shared bicycle campaign, also your help with the survey is greatly appreciated. I also want to thank Lara. Despite also not being my official supervisor, your help enhanced the quality of my survey significantly and your scientific background and experience helped me to get the desired results out of the survey. In general, I want to thank everyone who completed my survey, despite not necessarily knowing who these people are, they made this thesis succeed.

Thank you to my colleagues from Provincie Zuid-Holland. Not only for the help but also for creating a pleasant working environment that made my days at the office always enjoyable. I want to thank my friends from university, from back home and my roommates, for helping me through the harder times throughout my study, for the extensive amount of coffee breaks, for the evenings to the Kurk, the beers in PSOR and at home and all the amazing things I did with you during my study period. Finally, a huge thanks goes to my family for supporting me through it all. Whether I was complaining or celebrating, you were always there and that means the world to me. I also hope that you, the reader of this thesis, enjoy reading it and I hope it is useful to you and will provide you with new knowledge.

J. van Steen
Delft, December 2024

Summary

Continuous urbanisation and an increasing number of cars on the road have led to congested roads and increased emissions, leading to a demand for more sustainable modes of transport and the desirability of a modal shift to public transport (Batty et al., 2015). Companies more often settle in suburban areas and smaller cities where car commuting is dominant (Liu and L'Hostis, 2014), and the distance between transit stations and companies is often greater than one kilometre. Shared bicycles can serve this gap between the station and the office to enhance this sustainable shift (Kosmidis and Müller-Eie, 2024). The use of shared bicycles as the last mile is currently quite low and combined with the high car use in the suburban context, there is much to improve to optimise the use of shared bicycles.

Currently, shared bicycles are broadly integrated within more dense urban areas. However, this research focuses on the suburban integration of shared bicycles to determine how shared bicycles should be integrated within multimodal trips to optimally enhance the modal shift from cars to public transport for commuter trips. The study aims to identify which factors and system adjustments have the most significant effect on this modal shift and how this translates to integrating shared bicycles in suburban areas. The research aims to answer the following main research question to fill the current knowledge gap on the suburban integration of shared bicycles for commuting trips:

How can adjustments in the shared bike system enhance the use of public transport as the primary commuting mode, offering a viable alternative to cars in suburban areas?

This study begins with a comprehensive literature review to increase the understanding of the key factors that influence the use of shared bicycles and related sociodemographics. This review translates into a survey consisting of a revealed and stated preference component.
The revealed preference investigates current travel behaviour, attitudes towards shared bicycles, and knowledge of shared bicycles to identify (dominant) factors that promote bicycle sharing. It explores why respondents do or do not choose shared bicycles and public transport to gather insights into what affects the preference.
The stated preference survey focuses on hypothetical travel behaviour, analysed via a multinomial logit (MNL) model. This model estimates the value of literature and literature gap-based parameters, to quantify the effect of attributes on the modal shift to public transport and shared bicycles. The model is estimated based on attribute levels and the respondent's choice, starting with a base model consisting of fundamental parameters. To further specify the behavioural model, sociodemographic interaction parameters are subsequently incorporated.
This survey was distributed online via Qualtrics among respondents who commute to suburban areas. South Holland is used as a case study to explore the suburban potential of shared bicycles. The link to the online survey was distributed via channels such as LinkedIn, but also by flyering around train stations.
The stated preference model is applied in two ways to derive concrete conclusions on stimulating shared bicycle and public transport usage. First, a simulation is performed using demographic data from the population of South Holland, with commuting trips to Drechtsteden and Leiden as case studies. Second, a persona-based simulation is performed for a more in-depth analysis of how socio-demographic factors influence the mode choice. The methodology is visualised in Figure 1.

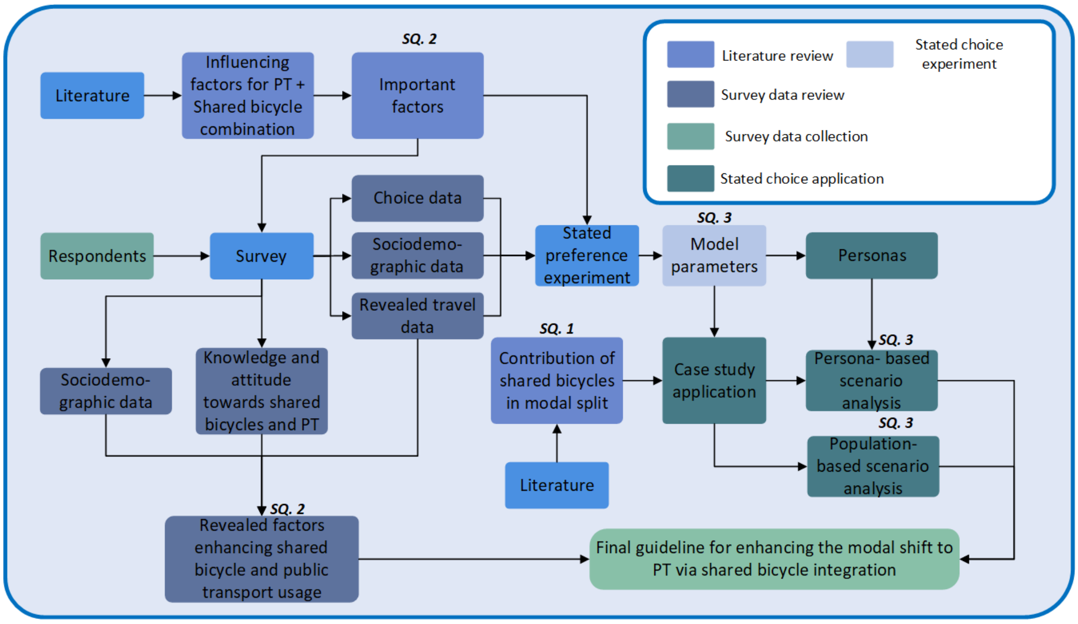

Figure 1: Methodological framework

The results of this research are based on the responses of 105 respondents. Their revealed behaviour shows that younger and higher educated respondents are the most dominant public transport users. Revealed and attitude-related data also show that car parking costs correlate with higher use of public transport. A key finding is the critical role of competitive public transport travel times compared to commuting by car. For many respondents, the longer public transport travel time reduces the likelihood of considering bicycle sharing. Almost all respondents willing to use shared bicycles, only consider this in combination with public transport, emphasising the importance of synergy between public transport and bicycle sharing in suburban areas.
The survey and literature study indicate that shared bicycles are most effective as an egress mode for last-mile distances between 500 and 3000 metres. This highlights that bicycle sharing potential is highest for companies within this distance from a station. A frequently mentioned barrier is the unavailability of shared bicycles. This increases the uncertainty and lowers the willingness to adopt shared bicycles for their last mile. The shared bicycle is often not considered due to the ownership of a private bicycle at the destination-side station. The study also highlights some cost incentives that stimulate shared bicycle usage. Employer incentives to incorporate shared bicycles into the public transport card or memberships for shared bicycles, where costs are, for example, monthly instead of pay-per-use, show high potential. The results also highlight the importance of good bicycle parking at work to stimulate (shared)-bicycle usage.

The stated preference experiment amplifies the results of the revealed preference for the importance of travel time and costs. The model highlights a general preference for the car via the alternative specific parameters. Furthermore, one extra monetary unit for shared bicycles is generally valued three times as negative as one minute of additional travel time. The model also highlights a general preference for shared bicycles available for 24 hours. However, this depends on the socio-demographics. Older and frequent travellers show a relative preference for single-use systems compared to the baseline traveller. Rental costs are experienced twice as negatively by younger (-0.529/€) and low-income travellers (-0.487/€) than the baseline traveller (-0.245/€), while parking costs are prone to no sociodemographic interaction effects. Public transport travel time is experienced worse for women and lower-educated respondents. In contrast, car travel time is perceived as less negative for frequent, high-income travellers who are current car users.

The simulation shows a significant effect of the cost incentives: Free shared bicycles and introducing car parking costs. However, this research discusses the benefit of free shared bicycles over car parking costs to allow for inclusivity for all commuters. A hybrid, single-use shared bicycle system is only effective when the hub location is optimised which minimises the egress travel time. Shared bicycle parking should be relatively close to the company to enhance the modal shift. The simulation also strengthens the argument on the need for competitive public transport for shared bicycles to succeed. The case study for Drechtsteden, where the difference in travel time between public transport and the car is higher than in Leiden, coupled with the sensitivity analysis on this ratio and the scenario effects, shows a significantly reduced marginal impact on shared bicycle usage when public transport is less competitive. Moreover, this study found that shared e-bicycles minimally enhance shared bicycle usage in suburban areas given the high preference for commuting by car when the last mile distance is larger.

This research concludes that improving the successful integration of shared bicycles and public transport in suburban South Holland is strongly influenced by competitive public transport travel times compared to cars. A large difference between travel time by public transport and by car diminishes the potential for bicycle sharing and public transport. Second, shared bicycle availability in high-demand areas is crucial, as inconsistent access discourages adoption. Cost measures, such as employer subsidies, paid car parking, and reduced fees for shared bicycles, significantly promote a shift from cars to public transport. A combination of paid parking for cars and free shared bicycles shows a potential modal shift of 10 percent-point related to the base scenario, where paid parking for cars mostly induces a shift to just public transport. Hybrid bicycle systems such as Donkey Republic suit frequent commuters, while e-bikes provide limited added value in suburban areas due to the high competitiveness of the car when egress distances are larger. Literature adds the need for synergy between transit and bicycles. Specifically in a suburban context, a quick and effortless transition between the modes is desired to enhance this synergy and stimulate the modal shift.

These results and conclusions bring forth a set of recommendations. Cost incentives are essential to improve the adoption of shared bicycles in suburban areas, especially where public transport can compete with cars in terms of travel time. Integrating shared bicycles into business public transport cards, such as the NS Business card, and introducing memberships for bicycle sharing is recommended to reduce cost barriers. Introducing car parking costs is advised to stimulate the modal shift, but should be combined with the above-mentioned cost incentives to enhance public transport and shared bicycle usage.

In terms of parking policy, the province of South Holland should consider reallocating some regular bicycle parking spaces in suburban stations to dedicated shared bicycle parking, addressing the availability issue and enhancing the shift from private to shared bicycle. A specific investment in the 'Wisselfiets' concept is advised. Furthermore, a combination of shared bicycle systems (Donkey Republic and OV-Fiets) should be implemented, focussing on transport integration with non-electric shared bicycles. This recommendation is based on a diverse demand for shared bicycle systems, as retrieved in the persona-based simulation. This to increase availability and satisfy this demand for various systems. Furthermore, municipalities and the province should cooperate to improve hub locations and transferability to shared bicycles, and stimulate usage and knowledge with their initiatives.

Future research should consider more advanced modelling techniques, such as mixed and panel mixed logit to capture heterogeneity across public transport alternatives and the correlations across choices made by the same individual (van Cranenburgh, 2023). However, more data is advised to work with these more advanced models (Rainey and McCaskey, 2021). More research on real-time travel behaviour monitoring during shared bicycle pilots can further sustain policy development. The current research addresses mostly stated preference behaviour and revealed behaviour in terms of attitude and knowledge but could benefit from more in-depth revealed travel behaviour on public transport and shared bicycle combinations in suburban areas.

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Introduction

1.1. Research context

On a global scale, continuous urbanization and increasing urban trips lead to a large challenge in sustainability and the urban environment. Since the modal split of commuting trips has not changed much over the last decades, congested roads during peak hours and air pollution have become more common. This all leads to a demand for a shift towards public transport (Batty et al., 2015). Due to this constant urbanisation, companies often establish in areas around but outside the larger cities, which can be identified as suburban areas (Forsyth, 2012). Companies in these areas, mostly located between 1 and 4 kilometres from public transport stations are prone to high car usage for suburban commuting. Commuting car usage in high suburban areas can go up to 75 %, whereas public transport is only considered by 10 % (Liu and L'Hostis, 2014). Moreover, Dutch data shows a modal split of 6 to 10 % of public transport for commuting trips in suburban areas, where the car is used for 60 % of those trips (Centraal Bureau voor de Statistiek, 2024f). A critical component in the public transport journey is first and last-mile transport. Door-to-door accessibility can sometimes be challenging with just public transport, certainly when companies are located a few kilometres away from a larger transit station. Still, an effective public transport multi-modal network should aim to serve as many people as possible (Smith et al., 2018). One of the ways to provide last-mile transport is by use of shared bicycles as shown in Figure 1.1, which is proven to be an efficient mode to serve complementary to public transport performance and usage (Kosmidis and Müller-Eie, 2024).

Figure 1.1: Shared bicycle concept at railway station (Studio Alphen, 2023)

The Province of South Holland strives to expand shared bicycle usage in mobility hubs and stations. Currently, mostly other modes, mainly by foot or by bus, tram, or metro (Torabi et al., 2022) cover the last mile due to the sometimes low availability of these shared bikes and the ease of using the car as an alternative for transit. The province strives to achieve ten times more people using bicycles as a

last-mile solution from mobility hubs (A location where one or more transit modes are co-located with shared mobility (Intertraffic, 2021)). The province's vision aligns with many studies showing that shared bicycles are underused as a last-mile solution but offer many possibilities in practice (Heinen and Bohte, 2014). However, it is yet unknown whether this will increase the use of shared bikes and result in a modal shift toward the combination of public transport and bicycles (Norén, 2024).
The problem that shared bikes are often unavailable is not unsolvable. However, the problem is that the stations usually offer too little space for shared bikes and are occupied mainly by personal bikes that stay there for multiple days without use. In contrast, shared bikes also occupy less space per individual bike (Norén, 2024). Furthermore, it is stated that under 2 % currently use the shared bike as a mode of transport for the last mile and that in a suburban context, where offices are often further away from stations or hubs, public transport combined with shared mobility for the egress trip is rarely used due to the advantage of the car. Experts comment that without a shared bike system in stations, 8 % will instead use a car for door-to-door transport (Bruntlett, 2024), which implies the importance and possibilities of a shared bike system in combination with transit. The problem is therefore that there is an urge for a modal shift to public transport and active modes to decrease car traffic and make commuting traffic more sustainable. It was proven that a well-designed shared bicycle system enhances this shift in travel behaviour since there is a shortage in the current system for destinations located further from the stations (Kosmidis and Müller-Eie, 2024). This raises the problem that the shared bike system should be investigated to enhance public transport and shared bicycle usage.

1.2. Research problem

The transition towards sustainable mobility is becoming increasingly important within scientific research, particularly in addressing the potential of public transport and active modes such as shared bicycles to reduce car dependency. Existing studies, like those by Ma et al. (2020), Van Kuijk et al.(2022) and Ton et al. (2020), have analysed bike-sharing systems, public transport last mile alternatives and commuting mode choice in dense urban contexts, examining their impact on the modal split and promoting sustainable travel options. However, there remains a research gap in the literature concerning the effectiveness of shared bicycles in less dense, suburban areas where public transport infrastructure is often limited and car usage is predominant.

Current research mainly focused on urban areas where shorter distances allow for better integration of shared bicycles with public transport. In a suburban context, however, there is little to no in-depth research considering the expansion of shared bicycle usage. This is sustained by Table 1.1 that summarises the literature study from the prepatory phase of this thesis. Longer egress distances, a higher reliance on car usage and higher car usage rates (Zijlstra et al., 2022) present challenges to shared bicycle integration and a modal shift to public transport that are not well-addressed in the existing body of literature and where the existing knowledge is scarce (Montes et al., 2023; Boting, 2023). Thus, in-depth research on these areas can further map and enhance the potential for public transport and shared bicycles.
To bridge this literature gap, this research investigates the potential for shared bicycle integration within suburban areas, focussing on factors that could make public transport and shared bicycles more appealing to commuters. Furthermore, existing literature mainly focuses on the modal split of different egress modes (van Kuijk et al., 2022) or between shared mobility and urban public transport, where shared bicycle possibilities are mostly addressed. This raises a point to further expand the current body of literature by investigating the role of solely shared bicycles and their contribution to commuting trips. There is also room for research on the shift from car users to public transport. The car is now mainly integrated as an alternative option considering modal split for current shared bicycle users (as also investigated by Barbour et al. (2019)). This research will therefore zoom in on the current car users and how to let them switch to public transport and bike sharing as mode of transport.

Table 1.1: Literature overview on shared mobility for gap identification

Paper	Egress mode	Scale	Multi-modality
Yan et al., 2019	University shuttle, bike, car and Walking	Urban	Yes
Torabi et al., 2022	Bike, E-step, E-Moped, Automated vehicles	Urban	No
Adnan et al., 2019	Shared bike	Urban, Suburban	No
Campbell et al., 2016	Shared bike and e-bike	Urban	No
Jäppinen et al., 2013	Shared bike	Urban	Yes
Fan et al., 2019	Bike	Urban	No
Bachand-Marleau et al., 2012	Shared bike	Urban	Yes
van Marsbergen et al., 2022	Shared bike	Urban	Yes
Brand et al., 2017	(Shared) bike and walking	Urban	Yes
van Kuijk et al., 2022	Bicycles, e-bikes, e-scooters, e-mopeds, e-cars, LEVs, demand-responsive taxi services	Urban, Suburban	Yes
Barbour et al., 2019	Shared bike	Urban	Yes
Montes et al., 2023	Shared bike, E-moped and walk	Urban	Yes

1.3. Research objective

The objective of this research project is to investigate what drives commuters in suburban environment to use the shared bicycle system in combination with public transport. It aims to create a guideline of what system measures to implement to improve the last-mile trip with shared bikes and thereby encourage a modal shift towards public transport and shared bicycles.
This guideline tries to answer which shared bicycle system improvements suit the public transport network in more suburban areas, using South Holland as a case study. It aims to answer what drives travellers to use current public transport with shared bike combinations. This guideline aims to enhance a shift from the car towards public transport.

To establish this, methods related to the users' choice behaviour are applied to obtain insight into the effect of different adjustments in the shared bike infrastructure. In addition to the current set of literature, this research will thus add more insight into the improvements possible for the shared-bike system in suburban areas and therefore the improvements of the whole public transport system including last-mile trips to be a more favourable option compared to commuting by car.

1.4. Research scope

This research is scoped down to only commuting trips. In other words, from home to work and the other way around. Furthermore, the focus is on new users who can switch from car usage to public transport if last-mile transport is increased, for the last mile, the research focuses on only the shared bike as a last-mile option and disregards other egress modes. The research area is limited to suburban and more regional areas in the province of South Holland. This area holds a great ambition of enlarging shared bicycle use, has the most room for improvements and the least research is conducted on suburban areas. In this research, the public transport and shared bicycle combination is just considered as a mode to substitute trips completely taken by car. Hence, using the car as an access mode or getting dropped off at a station by car are not taken into account in this study.

1.5. Research questions

This research seeks to explore the knowledge gap on shared bicycle potential in a suburban context to gain an understanding of how shared bicycles could enhance commuting by public transport instead of by car (Montes et al., 2023; Boting, 2023; van Kuijk et al., 2022); Barbour et al., 2019). Therefore, the main research question of this study is as follows:

Main Research Question:

How can adjustments in the shared bike system enhance the use of public transport as the primary commuting mode, offering a viable alternative to cars in suburban areas?

To answer this research question, the following sub-questions are derived:

1. *What role do shared bicycles play in shaping the modal split, particularly in improving connectivity to public transport for suburban commuters?*
2. *What elements influence the usage of shared bicycle systems?*
3. *To what extent will commuters change their travel patterns and mode choices in response to changes in bicycle-sharing infrastructure, public transport and measures discouraging car use?*

1.6. Research methods

A research methodology used in this thesis is a survey, conducted in suburban South Holland, combining revealed data collection and a stated preference experiment to determine the respondent's travel behaviour, attitude towards shared bicycles and choices in different stated situations. The attributes of the shared bike systems that will be investigated will mostly be retrieved from literature research. The goal is to determine the effect of different attributes concerning the last-mile trip by maximizing the likelihood of the model established in this research (Rose and Bliemer, 2009). The revealed data gives a comprehensive overview of the current travel behaviour of the respondents in combination with data about why they will or will not consider public transport and shared bicycles. The stated choice experiment is a complementary method to investigate hypothetical situations that may improve the shared bike system, for example, the use of e-bikes. This will together provide a complete overview of insights into the effect of current attributes and measures and possible extra measures. These measures are translated into specific recommendations via a general and persona-based simulation.

1.7. Contribution to science and practice

This thesis is socially relevant because it considers ways to improve bike-sharing systems to enhance the usage of public transport in combination with a shared bicycle instead of a car. Car usage becomes more problematic in terms of pollution and congestion on the road network (Batty et al., 2015). Experts comment on an increase in traffic jams of 17 % since last year and expect 25 % more cars in 2030 compared to 2019 (Voermans, 2024). A shift to public transport can be a solution when designed optimally. By conducting this research, the Province of South Holland has more insight into how to improve their bicycle sharing systems in more suburban environments to invest in and extend their infrastructure of shared bicycles. The vision of South Holland is to get as many people as possible to cycle where the greatest challenge is in commuting trips. The conclusions of this thesis will help policymakers and engineers in the province of South Holland meet this vision through the modal shift enhanced by the measures found in this research.

Scientifically, this research contributes to the existing gap in research on shared mobility, especially shared bicycles and modal shifts. It will provide more in-depth results on how people regard shared bicycle systems, how a modal shift can be enhanced for commuting to a suburban environments, and how this differs from the current findings in more urban regions. This insight in suburban commuting is currently underexposed study area.

1.8. Thesis outline

Chapter 2 will be dedicated to a literature review where the state-of-the-art on shared bicycles and its relation to public transport and car usage is investigated. Chapter 3 of this thesis elaborates on the methodologies used in more detail. Furthermore, the literature review will aid in determining which attributes of shared bicycles, cars and public transport influence the modal shift. Chapter 4 will discuss the design of the survey, where the revealed preference and the stated preference are further worked out in terms of structure, type of questions and model design. Chapter 5 will then discuss the revealed results, where revealed travel behaviour and the attitude towards shared bicycles are combined and commented on. Chapter 6 will follow the stated preference experiment with a discrete choice model to analyse the survey data and determine which attributes contribute to the modal shift and to what extent this happens. Chapter 7 elaborates on the implementation of the results and how the shared bicycle system can be improved given the desire for a modal shift. This thesis is concluded with Chapters 8, 9 and 10 which cover the conclusion, discussion and recommendations for further research and the province respectively.

2 Literature Review

This chapter provides a comprehensive literature review on shared bicycle systems, multimodal travel patterns, and modal shifts. It aims to identify the factors, policies, and socio-demographic characteristics that influence mode choice. This establishes a foundation for the survey to examine how shared bicycles combined with transit can promote a modal shift from cars to public transport in suburban areas. The literature review continues from the literature that determined the research gap in which the main focus was on current methods, attributes, target groups, and study scale (urban, suburban, rural). To perform this literature review, Google Scholar is generally acknowledged, where sources such as ScienceDirect and ResearchGate are retrieved. The snowballing method is applied for a more thorough analysis of the topics discussed in the paper. This method holds that from earlier investigated papers, other papers, cited in those specific papers, are acknowledged. The related literature focusses on additional and new information on the topics discussed in the review to create a more in-depth basis of the literature for this study. The sub-questions answered in this literature review are as follows:

Sub-question 1 - What role do shared bicycles play in shaping the modal split, particularly in improving connectivity to public transport for suburban commuters?
- Chapter 2.2

Sub-question 2 - What elements influence the usage of shared bicycle systems?
- Chapter 2.3

To answer these questions, Chapter 2.2 provides an in-depth analysis of the current findings on shared bicycle systems, as well as their connection to public transport and car usage. Furthermore, the current understanding of influencing factors that could encourage commuters to use a shared bicycle and public transport instead of a car is discussed in Chapter 2.3. Chapter 2.4 will discuss both topics from a Dutch perspective and elaborate on how a modal shift from car to public transport can be initiated and how shared bicycles can stimulate this shift.

2.1. Overview of the literature study

In the scheme presented below, the literature review approach is further visualised. Initially, the papers were identified by keywords and authors from TU Delft, as suggested by the supervisors of this research. These papers provide a good basis for the follow-up snowballing process per topic. As visualised in Figure 2.1, the keyword search gave 18 papers deemed useful for the literature review combined with 1 additional and 2 common papers from TU Delft-related authors. Via the snowballing method, an additional set of 23 papers is found, resulting in the 41 papers reviewed for this study.

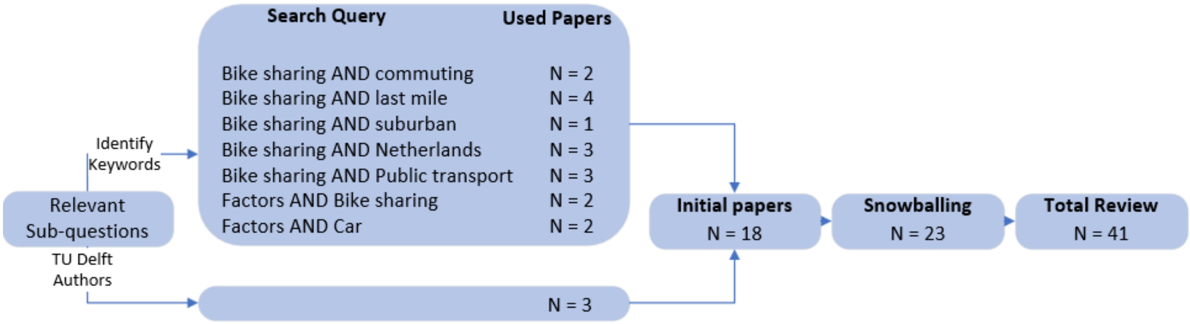


Figure 2.1: Flowchart of literature review workplan

To provide a clear overview of the literature used, Table 2.1 exhibits some insights into the year the literature was published, the corresponding journals and the message extracted from the papers.

Table 2.1: Summary of literature: Year of publication, purpose and journal

Year of publication	Use	Journal
2004 (1)	Role and implementation (5)	Applied geography (1)
2009 (1)	Synergy with Public transport (10)	Case studies on transport policy (1)
2010 (2)	Competition with car (10)	Journal for geographic information science (1)
2011 (2)	Factors enhancing shared bicycles (22)	Journal of advanced transportation (1)
2012 (3)	Sociodemographic effect on shared bicycle usage (12)	Journal of ambient intelligence and humanized computing (1)
2013 (3)		Journal of cleaner production (1)
2014 (3)		Journal of transport geography (5)
2015 (2)		Journal of transport health (2)
2016 (3)		Research in transport economics (2)
2017 (3)		Sustainable cities and society (2)
2018 (1)		Transport policy (2)
2019 (4)		Transport reviews (2)
2020 (7)		Transportation (2)
2021 (2)		Transportation Research A (6)
2022 (2)		Transportation Research C (1)
2023 (2)		Transportation Research D (2)
		Transportation Research F (3)
		Transportation Research record (3)
		Mineta transportation institute publications (1)

2.2. Integration of shared bicycle systems

2.2.1. Role and implementation of shared bicycle systems

To regard things from a general perspective, shared (micro) mobility can enhance the multimodal mobility of commuters, reduce vehicle ownership, and broaden travel flexibility (Shaheen et al., 2016). Shared bicycle systems also complement the demand for more eco-friendly mobility, where fossil fuel dependence is tackled and the goal of stimulating more healthy modes of transport is met (Fishman et al., 2014; Bachand-Marleau et al., 2012). Research by Shaheen et al. (2010) shows that there are clear hints that bicycle-sharing systems are beneficial for multimodal trips. The trips partly taken by public transport are complemented by a shared bicycle for the rest of the journey. Shared bicycles were integrated in different ways over time. Based on the paper of (Shaheen et al., 2010), Figure 2.2 describes how shared bicycle systems have changed over time and how they are integrated into the environment.

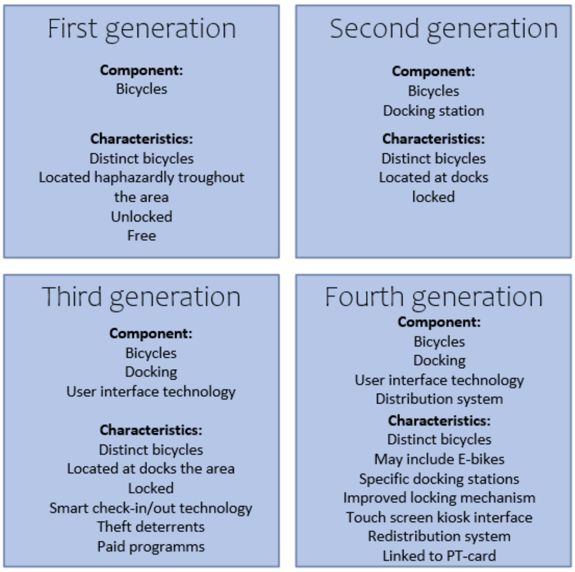


Figure 2.2: Generations of shared bicycles (Shaheen et al., 2010)

This scheme aligns with the generations and improvements of shared bicycles described by Chen et al. (2020). This paper relates the first generation of shared bicycles to the "Witte Fietsenplan" in Amsterdam in 1965. This system distributes white bikes without locks throughout the city available for anyone. Between 1991 and 2012, a sharing system in which coins function as keys to bikes was introduced in Denmark, which was the first system where locked bicycles were distributed that could be unlocked with that specific coin. In the early 2000s, the first docking stations were introduced for shared bicycles where users personally get and return the bicycle at a single specific docking station. Later on, the technical part of getting and dropping off the bicycle was integrated into the bicycle and not at the docking location. This offers more freedom in where to use the shared bicycle. The latest improvements in shared bicycle systems are hybrid and free-floating systems with electric keys and apps to unlock the bicycles. Furthermore, a connection with other operators is made to increase the interoperability of the shared bicycle system.

2.2.2. Bicycle sharing systems

According to Jorritsma et al. (2021), a shared bicycle system can be divided into several categories. The first category is a **station-based** shared bicycle system. This category can be split into two subtypes of systems: Roundtrip and one-way.

1. **Roundtrip**: In this system, Shared bicycles are located at a certain public transport station and after completing one's journey, the bicycle should be returned to the same station. The Dutch OV-Fiets system is designed as such a system. This system can also be referred to as **Back-to-one** (Rijkswaterstaat, n.d.).
2. **One-way**: The bicycles are located at a specified location or station. However, for this type of system, it is possible to return the shared bicycle to another area or station than the station from which it originates. A system where bicycles can be dropped off at multiple stations is also identified as **Back-to-many** in some literature (Rijkswaterstaat, n.d.).

The second category is a **free-floating** shared bicycle system. For this system, a dense network of dropoff points for bicycles is placed. Some systems even use Geofence technology to identify parking areas for the shared bicycle. In general, there is no parking infrastructure necessary for this type of system.
There is also a type of system that is a **hybrid mix** between station-based and free-floating bicycle sharing. Within this system, shared bicycles can be rented from a larger station and returned to multiple non-station-based locations throughout the area.

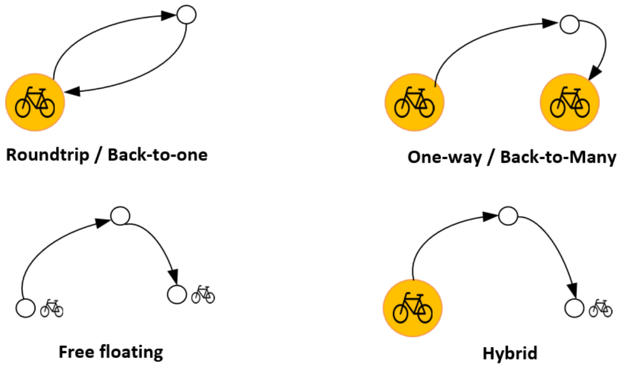


Figure 2.3: Visualisation of bicycle sharing systems

The Province of South Holland is introducing the "Wisselfiets" concept to diversify shared bicycle systems. In this system, the same bicycle is used for first-mile transport to the station and last-mile transport from the destination station to work for another user. In the afternoon, the bicycle supports reversed trips: from work to the station and from the station to another user's home. This dynamic system addresses challenges such as high demand for parking spaces and the availability of shared bicycles, promoting efficient and flexible use (Provincie Zuid-Holland, 2024b).

2.2.3. Synergy with public transport

There is great potential in combining public transport with the shared bike system. Shared bicycles and e-bicycles show capabilities to benefit public transport users in a mixed urban and suburban environment over other active modes, hinting towards the potential of the shared bicycle and public transport synergy in this context (van Kuijk et al., 2022). This combined system can sometimes even be treated as a single integrated system as believed by Kager et al. (2016). In the research by Fishman et al. (2015), 40 % of the Melbourne residents surveyed indicated that the reason for shared bicycle use is that it is an addition to public transport. For this combined system to function optimally, it is mainly important that the transfer is organised well. This results that the bicycles offer a significant increase in door-to-door accessibility and offer a more fine-grained spatial distribution of destinations that cannot be reached easily by public transport only (Kager et al., 2016), where also the last-mile connectivity issue is improved on (Jäppinen et al., 2013). A well-integrated system can be as accessible as a personal vehicle such as a car. Furthermore, Literature proves that the synergy between public transport and shared bikes leads to better sustainability, efficiency and equity of urban transport (Shelat et al., 2018). To reach this synergy, it is important to create well-designed infrastructure at transit stations, to invest in bicycle parking facilities, and in well-designed cycle infrastructure (Shelat et al., 2018). Well-designed complementation of shared bicycles with public transport benefits the use of shared bicycles. Australian research on bicycle sharing systems proves that by integrating shared bicycles in a public transport card, usage rates are expected to go up (Fishman et al., 2012). This system is comparable to using the OV-Chipkaart (Dutch public transport card) for the OV-Fiets (Shared bicycle system in The Netherlands).

Shared bikes can also substitute public transport trips. This is mostly the case in more urban areas where trip distances are smaller and only a shared bicycle is sufficient to compete with inner-city public transport (van Marsbergen et al., 2022). The scale and robustness of the public transport network and the city determine if shared bikes function as complementary or competitive. Furthermore, the competitiveness of bicycle-sharing systems with public transport depends on the competitiveness of travel time between the two modes (Leth et al., 2017). Moreover, Bachand-Marleau et al. (2012) conclude that if bicycle-sharing systems operate in the same area as public transit, mostly in urban areas, there can be a competitive element between the two modes of transport. This competitive element is also said for the last mile. Guo et al. (2021) describe a negative correlation between the number of bus stops close to a train or metro station and the number of shared bicycle trips. This denotes the shared bicycle potential in suburban areas, since the number of public transport lines providing last-mile transport is slimmer.

2.2.4. Competition with car usage

The preference for cars is defined by their speed, flexibility (Door-to-door without transfers, schedules and multiple modes of transport), safety and personal space (Carse et al., 2013). This research also mentions two important elements affecting why people commute by car. For commuters, the complexity of multimodal trips with public transport including first and last-mile solutions can discourage the shift from car to this multi-modal way of travelling (Schneider et al., 2020). Moreover, this study highlights that removing complexity also depends on the person and travel pattern and should preferably be studied on an individual scale. Multiple behavioural models described by Abrahamse et al. (2009) indeed describe the convenience of trips by car (Uni-modal and door-to-door (Jonkeren and Huang, 2024)) and the flexibility (departure time is not fixed) as the main drivers for commuting by car. Furthermore, environmental awareness shows a significant contribution to why people tend to use more sustainable modes (public transport + (shared) bicycle) (Abrahamse et al., 2009). If workplaces have free parking available, commuters own a car and if the distance from home to work is also relatively large, the car is considered a popular option. A case study in Washington highlights that free parking at work decreases the odds of bicycle commuting by 70 %, emphasising the important effect of this attribute. Besides parking availability as a stimulus for car use, traffic jam possibilities on the way to the destination have a significant influence on the willingness to commute by car (Buehler, 2012; Currie and Delbosc, 2011). One factor also often mentioned is the habit of using a car. Lanzini and Khan (2017) commented that most travellers who always use a certain mode of transport, predominantly use this mode for future trips.

bike-sharing systems can decrease the number of trips made by car, especially when combined with public transport (Ma et al., 2020, Teixeira et al., 2023). Bicycle-sharing systems have a smaller impact on car usage in larger cities, where highly connected public transport networks mean that shared bicycles often compete with, rather than complement, public transport modes. As a result, bicycle sharing contributes less to reducing car traffic. The car is already an inconvenient mode of transport in denser urban areas where other modes of transport are chosen for intracity trips (Fishman et al., 2014). However, various studies indicate a modal shift from cars to bicycle sharing from 1% to 21 %, varying among different bicycle sharing programs. The modal shift from car to bicycle-sharing also depends on the current modal split of the study area. In cities where the car is not considered one of the dominant modes, the shared bicycle will predominantly compete with other egress modes such as transit, walking and private bicycles (van Marsbergen et al., 2022).

2.3. Factors enhancing usage of shared bikes

To ensure that a shared bike system complements public transport and serves as a viable alternative to car travel, it is essential to study the factors influencing the adoption of shared bikes as part of the journey. The literature shows three categories of attributes: Physical attributes, the attributes related to the built environment and the shared bicycle infrastructure, external attributes, related to the experience and perception of travelling by shared bicycle, and sociodemographic attributes, consisting of the characteristics of the users or non-users.

2.3.1. Physical attributes

Physical attributes can be described as directly related to the bicycle and bicycle-sharing infrastructure. One such factor that directly influences the usage rates of bicycle sharing is the capacity of a destination docking station. It is concluded that when docking stations at the end of one's egress trip have a relatively high capacity, travellers are more likely to choose a shared bicycle over other modes of transport for the last mile (Faghih-Imani and Eluru, 2015). Hence, it can also be related to the willingness to shift from a trip by car to the same trip with public transport + shared bicycles. It is also worth investing in the built environment for cyclists to enhance travelling larger distances by (shared) bicycle. In other words, to create a cycle-friendly environment to increase the catchment area for shared bicycles (Leth et al., 2017). Ma et al. (2020) also mention that the quality perception of shared bicycles influences the willingness to use one. Good quality bikes positively correlate with their use. For commuting trips, the distance between work and the nearest docking station influences the adaptation of shared bicycles. Fishman et al. (2015) noted that when the working location is within 250 meters of a docking station, the adaptation rates of shared bicycles increase significantly.
The implementation of electric shared bicycles is also interesting to consider. Jorritsma et al. (2021)

comment that e-bikes are adopted for a wider range of distances due to their higher speeds. This is sustained by Campbell et al. (2016), where e-bikes are a fitting option for longer trip distances. Since suburban areas are considered and not necessarily every station-location trip is short, e-bikes are a good solution to consider. Often mentioned is the alternative of placing a second bicycle at the destination station. Krizek (2011) discusses this alternative to shared bicycles as a last-mile modality, but comments also on the disadvantages of a second bicycle. His research describes the concerns for theft and vandalism, the possibility of flat tyres and other issues when arriving at the station, which are also addressed by Teixeira et al. (2023) as opportunities for shared bicycles over a private bicycle. Although a second bicycle is not always a perfectly valued alternative as an egress mode, it could affect the usage of shared bicycles for the same purpose.

2.3.2. External attributes

One of the most influential factors that discourage bicycle sharing is the rental costs (Adnan et al., 2019; Montes et al., 2023). Furthermore, the egress distance per shared bike is also experienced negatively. However, for the usage of shared e-bicycles, this distance is experienced as less inconvenient than for regular shared bicycles (Campbell et al., 2016). A shared bicycle system shows optimal usage rates for certain travel distances. Bachand-Marleau (2012) found lower usage rates for very short travel distances but also for longer travel distances. For distances between 500 and 2000 metres, the shared bicycle is preferred over walking as egress mode (Fan et al., 2019). However, opinions vary on the optimal distance range; Some research comments that (shared) bicycles are the dominant mode up to a distance of 3500 metres (Heinen et al., 2010), while other studies give a smaller and lower range of 800 to 1500 metres (Guo et al., 2021). In addition to travel distance, it is also proposed to look at travel time, since this can be perceived by travellers differently than the travel distance (Ton et al., 2019). Time-saving is deemed an important factor considering the adaptation of shared bike systems. Especially in combination with public transport, little time loss must be achieved when switching from public transport to biking. Therefore, it is important that bicycles are easily accessible and that the transfer time between transit and bicycle should be minimised (Ma et al., 2020). Figure 2.4 shows the effect of distance and capacity on the utility of shared bikes. In this figure, it is also clearly visible at what range of distance people are willing to consider the shared bike as discussed earlier (Fan et al., 2019; Heinen et al., 2010).

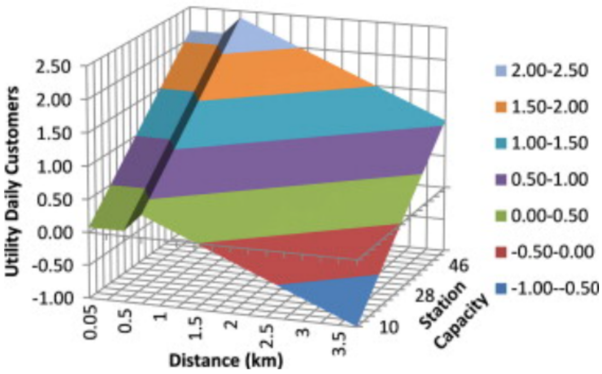


Figure 2.4: The effect of distance and capacity on the desire to use shared bicycles.(Faghih-Imani and Eluru, 2015)

The research expects that the availability of shared bikes at the public transport station/hub affects the attitude toward shared bikes in combination with public transport as the commuting mode. (Shared) bicycles are used mostly for access trips but are less often used for egress due to uncertain or low availability (Brand et al., 2017). However, this attribute is mentioned but not studied well yet (Fan et al., 2019; Heinen et al., 2010). Heinen et al. (2010) suggest a more in-depth study on the effects of bicycle availability and its impact on mode choice for commute trips. The frequency of commuting is expected to play a certain role in the willingness to adopt a shared bicycle. Low commute rates show a negative attitude towards the use of bicycle sharing. In contrast, travellers who spend a total of 90 minutes or more travelling a day will use bicycle sharing more often (Barbour et al., 2019). Also often addressed in the literature is the perception of safety while riding a bicycle. For many, it is a considerable barrier to use a bicycle-sharing system if the safety of that mode of transport is lower than that of, for example, the car (Fishman et al., 2012). In the case of the Melbourne bicycle-sharing system, the availability of helmets and the willingness to wear a helmet were two of the main factors for the low usage rates (Fishman et al., 2012). These factors are unimportant for this research since helmet legislation is not applicable in the Netherlands for bicycles. An important external attribute mentioned by Ton et al. (2020) and Nello-Deakin and te Brömmelstroet (2021) is the employer's role in modal shift stimulation. They state in their studies that travel allowance for (shared) bicycles could encourage employees to reconsider their mode choice and consider public transport and bicycles for their trip. Besides external effects such as costs, safety and availability, weather conditions also seem to influence bicycle-sharing usage. Dry and warm weather positively affect the usage of shared bicycles (Corcoran et al., 2014).

2.3.3. Socio-demographics

Concluded from the literature is that gender is also a key factor in determining how keen people are to use shared bikes for the last mile. Generally, men use shared bicycles more often than women for egress and access combined with public transport (Böcker et al., 2020). Another interesting finding is the correlation between gender and trip length. It is concluded that male travellers are less likely to take longer trips on shared bicycles, however, this same research concludes that the skewness in gender representation may bias this finding since most participants were male (Faghih-Imani and Eluru, 2015). Heinen and Bohte (2014) combine those findings to conclude that men mostly do a combined trip with public transport and a (shared) bicycle, while women more often cycle the whole uni-modal trip to work. Furthermore, the influence of age on the adaptation of bicycle sharing is studied quite extensively. In a study by Van Marsbergen et al. (2022), young people are more willing to adopt a shared bicycle. This conclusion coincides with the expected vitality of younger people compared to middle-aged people and the elderly.

Mode preferences are also dependent on the level of income (Fan et al., 2019; Shelat et al., 2018; Nello-Deakin and te Brommelstroet, 2021). They found that mostly lower income groups tend to use a public transport + (shared) bike combination and higher income groups strongly prefer using the car for the same trip. In Figure 2.5, the share per modality is visualized against the income range. Here lower incomes are the more left-located bars and higher income groups are the bars on the right of the plot.

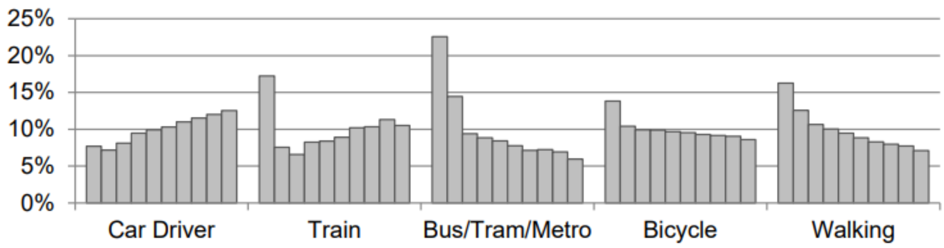


Figure 2.5: Effect of income on modality (Shelat et al., 2018). *Y-axis indicates standardised 10th percentiles income distribution; lowest = left*

This demographic is further researched by Barbour et al. (2019). They documented a high variation across respondents about how income affects the usage of bicycle sharing. Furthermore, they state that for bike sharing alone, higher-income groups have more affinity with shared bicycle systems than lower-income groups, which contradicts the findings about cycling in general in Figure 2.5. The fact that higher-income groups are more willing to use shared bicycles is also often considered together with the education level (Heinen and Bohte, 2014). This research states that using the combination of public transport with bicycle sharing could be due to higher-income jobs which require sometimes higher education and specialisation are more widespread and require longer travel patterns which are filled in with bicycle sharing and public transport. Generally, literature shows that there is more affinity with ride-sourcing with shared bicycles for people living in more densely populated areas where the job density is also higher (Barbour et al., 2020). This indirectly implies the challenges for bicycle sharing in more suburban areas, since the adaptation rate for shared bicycles is found to be lower than for highly urban environments.

As studied by Barbour et al. (2020), some more household-related characteristics are mentioned that possibly affect the usage rates of bicycle-sharing systems. This research also found that people with children are less willing to take shared bicycles to work than people who do not have children. Furthermore, car ownership significantly affects the inclusion of bicycle sharing in a multimodal trip. Both findings are sustained in research by Santos et al. (2013) who conclude a negative influence of car ownership on the willingness to use public transport + shared bicycles and who found that households with children tend indeed more to adopt a car for their commuting trips than public transport. Related to the findings about car ownership, research on the multi-modal trip, which considers more the global mode choice than the choice for shared bicycles, finds a similar conclusion. The literature shows that 80 % of multi-modal transport users do not have access to a personal car, which further emphasises the relation that car ownership affects the usage rates of shared bicycles in a multi-modal trip (Krygsman et al., 2004). Besides the ownership of vehicles, the ownership of a driver's licence plays a role in the modal split. Having a driver's licence harms the willingness to choose a shared bicycle/travelling via a multi-modal trip, thus ensuring more car ridership (Eren and Uz, 2020).

2.4. Lessons from Dutch studies

Besides scientific research, Dutch mobility institutions and other governmental organs perform research and pilots to identify how bicycle sharing could be enhanced, especially in combination with public transport. A shared-bicycle pilot in Leiden concluded mostly technical aspects that benefit the usage rates. Well-functioning locks and also the quality of the bicycle (as also mentioned by Ma et al. (2020)) enhance the willingness of travellers to use these shared bicycles (Mobycon, 2021). On the OV-Fiets, this research adds to the price constraint the low possibilities for station-home trips, since the OV-Fiets cannot be kept for a long time at the "lowest" fare rate.

A report from KiM (Kennisinstituut voor Mobiliteit) discusses literature and data about motives for shared mobility. They conclude, in line with some studies discussed in this chapter, that inhabitant density and bicycle infrastructure are the main factors of the built environment and that time, costs and flexibility are influential factors concerning the ease of use. In terms of attitude, mostly pro-environment visions are brought to light. Considering integration with public transport and ease of use, this report comments that the implementation of MaaS (mobility as a service) could benefit the potential of shared bicycles. For potential users, for example, users that currently commute by car, three main barriers are identified by the KiM. They define a lack of knowledge of shared bicycle systems, availability issues and the lack of technological knowledge of the users as those barriers. This technological knowledge can be further explained as the knowledge of apps used for bicycle sharing and how to work with those applications (Jorritsma et al., 2021).

To the pro-environmental drivers for a switch in modality, Jonkeren and Huang (2024) add the need to ensure that commuters keep using sustainable modes of transport. They comment that it should be discouraged that the car becomes the mode of transport again after major life changes, such as having a child. Furthermore, investments in paid car parking, public transport fees and infrastructure for (shared) e-bicycles are mentioned as measures to stimulate the modal shift to public transport (Jonkeren and Huang, 2024).

The study from Jonkeren and Huang from the KiM (2024) concludes the following on modal shift potential: The bicycle is found to be an essential mode to enhance this modal shift. If walking, tram, metro or bus is the only available last-mile transport option, the shift towards public transport is significantly lower. They reason that this is because bicycles offer better transfer comfort and transfer time and compete with walking in terms of speed. Furthermore, Jonkeren and Huang (2024) state that electric bicycles offer huge possibilities to enhance this shift. However, they mention that for the first mile, safety against theft should be guaranteed, but as a last-mile solution, e-bikes could be considered a great stimulus for public transport usage.

2.5. Conclusions

2.5.1. Implementation of shared bicycles

Shared (micro) mobility and thus shared bicycle systems contribute to possibilities in multi-modal travel chains, reduction of vehicle ownership and sustainable mobility. Bicycle sharing has proven to be a useful tool to broaden the service area of public transport systems by investing in the first and last mile of the multi-modal chain. Bicycle-sharing systems have evolved from simple easily distinguishable bikes distributed randomly throughout the city to a well-functioning system with docking systems, applications for finding and unlocking the bicycles and advanced integration with public transport for some systems. To design this combined system well, good transfer-ability, well-designed parking facilities and docking locations and a good integration via the OV-chipkaart must be considered thoughtfully. For Bicycle-sharing systems to synergize with public transport, it is important that both systems not compete in terms of travel time. Especially in more urban environments, shared bicycles are more of an alternative to public transport than a complementary mode. So in conclusion, in a more urban environment shared bicycles compete with public transport and therefore decrease the percentage of public transport usage and increase the share of shared bicycle usage. However, the potential for synergy with public transport where the modal split for both modes is positively affected is also visible in urban areas but more extensive in suburban areas. In both cases, shared bicycles can decrease the share of car trips.

In the Netherlands, four types of shared bicycle systems. Bicycles can be docked and returned to the same (**back-to-one**) or some other (**back-to-many)** docking station. Furthermore, bicycles can also be independent of specified docking locations (**free-floating**) or can combine both systems where docking locations are combined with free parking (**hybrid)**.

2.5.2. Influencing factors and important attributes

An important finding from the current literature is the ”why” and the ”why not” in the functioning of shared bicycle systems to be integrated with public transport and how this could compete with car traffic. Two general findings that are quite recurrent in most papers are **costs** and **travel time** or **egress distance**. Numerous studies conclude that the effect of travel costs is negative toward any mode of transport, whereas the reviewed studies found this relation for shared bicycles. The same negative relation was found for travel time and distance, whereas for egress distance most studies identified a range between 500 and 2500 meters to be optimal for bicycle usage. For e-bicycles, the distance considered convenient is higher than this range. Related to time-saving, a positive effect on shared bicycles is **transfer to bicycle** and **accessibility of bicycles**. A factor expected to affect shared bicycle usage negatively is **availability of shared bicycles**. However, there is a lack of in-depth study towards this attribute yet. From a traveller's point of view, the **travel frequency** and the **bicycling safety perception** are considered influencing factors, where a good safety perception positively correlates with usage rates. The infrastructure around bike-sharing is also important according to the literature. **Capacity of docking stations** and **cycling infrastructure** should be sufficient to stimulate people to commute by shared bicycle for their last mile. For commuting purposes, the literature showed that the **proximity of docking stations** is important to enhance shared bicycle usage for back-to-many shared bicycle systems. Furthermore, the **quality of bicycles** can positively influence the user rates according to some studies. Lastly, it is found that the **implementation of e-bikes** also benefits longer distance bike sharing needs. As included in various studies, **Weather** affects bicycle usage quite strongly. This effect is visible for commuting trips and private or recreational purposes.
Dutch studies add some valuable insights into why some commuters do not use shared bicycles. **Technological and knowledge gaps** are for many people's reasons not to use the shared bicycle. Many people lack knowledge about how bicycle sharing works and the existence of shared bicycles at stations. Moreover, many struggle to use shared bicycles due to applications necessary for use. Furthermore, Literature showed that having a **second bicycle at a station** will negatively affect the usage rates of shared bicycles. However, some negative effects of a private bicycle at a station are found, which can stimulate shared bicycle usage, when properly offered to the travellers.

In terms of sociodemographics, most studies agree that **gender**, **age** and **income** are determinants of the adaptation of shared bicycle systems. Mostly younger, higher-income men are willing to use a shared bicycle system. However, there are also some findings that men disregard longer bicycle trips for egress and some papers that show that bicycle usage negatively correlates with income. Concerning household characteristics, **having children**, **owning a vehicle** and **having a driver's licence** negatively affect the use of shared bicycles according to currently existing research.

Arguments for car usage that were found in various studies were mainly **Comfort**, **Flexibility** and **Availability of parking at work**. A driver not to use a car is the attitude towards the environment of the commuter since people who care more for the environment tend to use public transport and cycling. Furthermore, the **habit** of driving a car is mentioned as an additional driver for car usage in the future instead of an easy adaptation of sustainable mobility.

To identify which factors to introduce in the survey, the more dominant factors out of the summarising section are determined. Basic factors used in multiple scientific studies and regarded as of great influence on bicycle sharing and the mode choice for a commuting trip are costs, travel time or distance and the egress distance from station to destination. Hence, it is important to incorporate this in the revealed and stated preference experiments. A few papers also comment that the availability of shared bicycles can be important for usage and that some research on this topic is necessary, the survey therefore aims to identify some knowledge about the effects of bicycle availability. Multiple papers comment on the effect of parking availability and docking station capacity. This leads to the incorporation of car and bicycle parking-related factors that according to the literature affect the mode and egress choice. E-bicycles are adopted in some papers as a solution for longer egress distances. In suburban areas, this could be beneficial and thus this attribute is highlighted in the literature study. Most studies that investigate mode choice and shared bicycle usage also adopt socio-demographic attributes to search for the effect of socio-demographics on mode choice. Hence, these socio-demographics will also be in the survey.

Table A.1 in Appendix A summarises the factors that influence the use of cars and shared bicycles in combination with public transport. This gives a clearer overview of what has been identified and how these findings are justified. Furthermore, Table 2.2 considers the important part of Table A.1, as discussed in the second part of section 2.5.2. These dominant influencing attributes form the backbone of the survey design, as further elaborated in Chapter 4. Furthermore, a conceptual model is established and visualised in Chapter 4. This framework categorises the attributes identified as important and translates them into how they affect the modal shift for suburban commuting trips.

Table 2.2: Important literature-based influencing factors on public transport and shared bicycle usage

Factor	Paper(s)	Effect
Costs	Adnan et al., 2019; Montes et al., 2023	-
Travel time	Ton et al., 2019	-
Egress distance	Bachand-Marleau et al., 2012; Fan et al., 2019; Heinen et al., 2010	-
Availability	Brand et al., 2017; Fan et al., 2019; Heinen et al., 2010	+
Safety perception	Fishman et al., 2012	+
Lack of knowledge	Jorritsma et al., 2021	-
Well-designed cycling infrastructure	Leth et al., 2017	+
Second bicycle at station	Krizek, 2011; Teixeira et al., 2023	-
Bicycle parking proximity	Fishman et al., 2015	+
E-bikes	Jorritsma et al., 2021; Campbell et al., 2016	+
Good transfer-ability to bicycles	Ma et al., 2020	+
Car parking availability	Buehler, 2012; Currie and Delbosc, 2011	-
Gender	Böcker et al., 2020; Faghih-Imani and Eluru, 2015; Heinen and Bohte, 2014	Male (+)
Age	van Marsbergen et al., 2022	Young (+)

Income	Fan et al., 2019; Shelat et al., 2018; Barbour et al., 2019; Nello-Deakin and te Brommelstroet, 2021	High (+)
Vehicle ownership	Santos et al., 2013; Krygsman et al., 2004	-
driving licence	Eren and Uz, 2020	-
Travel frequency	Barbour et al., 2019	+
Education	Heinen and Bohte, 2014	High (+)

3 Methodology

This chapter describes the methods used in this research to answer the main research question: *How can adjustments in the shared bike system enhance the use of public transport as the primary commuting mode, offering a viable alternative to cars in suburban areas?*

Based on the literature research results, as reported in Chapter 2, the sub-question: *What elements influence the usage of shared bicycle systems?* is further elaborated on in the revealed preference part of the survey to explore aligning and new factors regarding influence on shared bicycle usage.
The sub-question: *To what extent will commuters change their travel patterns and mode choices in response to changes in bicycle-sharing infrastructure, public transport, and measures discouraging car use?* is answered through the stated preference analysis via a survey and is extended by a general and persona-based simulation to further quantify the results. The total set of analyses will provide enough information to answer the main research question. Figure 3.1 summarises the methodology applied for this research. This scheme visualises the sequential steps, the relations among each other, the sections dedicated to each step, and the corresponding sub-questions that are answered in each part.

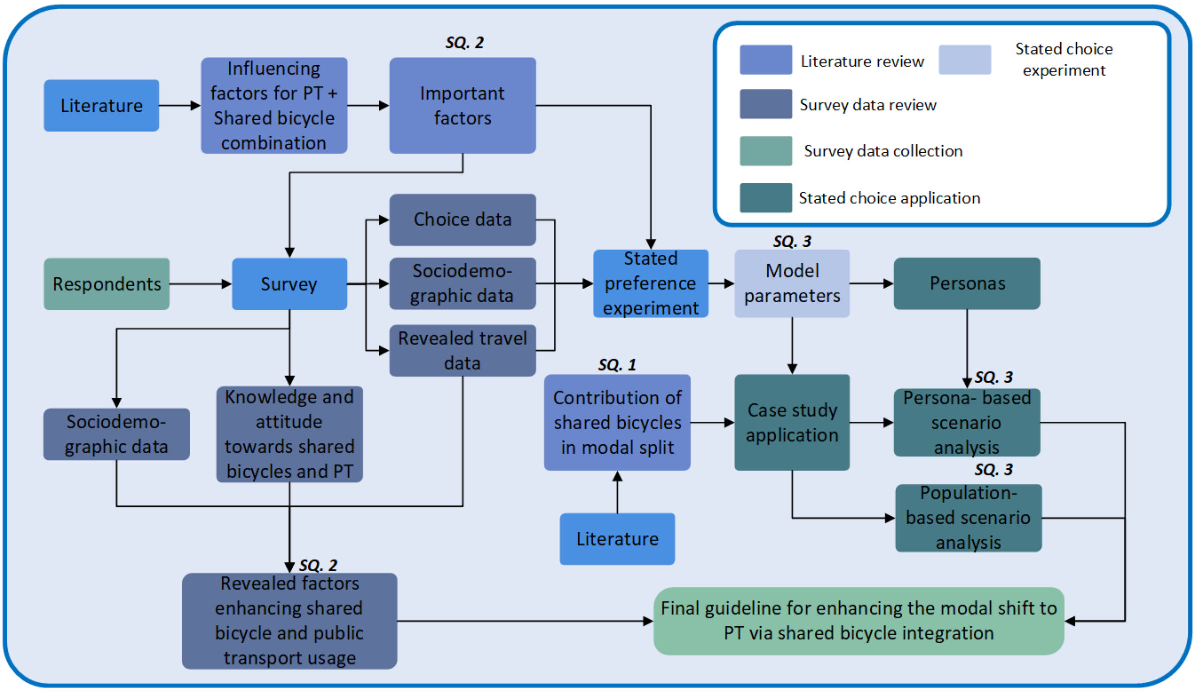


Figure 3.1: Methodological framework

3.1. Survey

This method applied to investigate suburban commuting behaviour and the possibilities for a modal shift to public transport and shared bicycles builds upon the attributes discovered in the literature analysis. This method includes a survey distributed among suburban commuters in South Holland, split into two parts to capture two key perspectives. The first part of the survey investigates actual commuting trips and the attitudes and knowledge of bicycle sharing. The second part of the survey will consist of a stated preference analysis used to discover how commuters value travel time versus costs and how the mode choice will change if elements of the bicycle-sharing system change or the car is discouraged. A revealed preference focuses on the actual market situation and actual behaviour and opinions within the state-of-the-art system, where stated preference is based on behavioural intentions and responses in hypothetical choice situations (Ben-Akiva et al., 1994). Combining these two methods will give a comprehensive overview of how people act and say they will act in a current and hypothetical situation. The choice for conducting a survey is sustained by methodologies of comparable studies (Revealed and stated preference) on mode choice (van Marsbergen et al., 2022; van Kuijk et al., 2022; Montes et al., 2023) and the lack of data to provide the desired understanding on shared bicycle potential in suburban areas. A survey is furthermore suitable to explore the existing data gap and gather new information on a larger sample of individuals (Anheier and Scherer, 2015): In this study, suburban commuters in South Holland.

3.1.1. Revealed preference

Design and goal

The revealed mobility research consists of two parts that will coincide to determine the travel behaviour and position of commuters towards shared bicycle usage. The survey will initially investigate which mode choice the commuter takes combined with insight into their first and last mile to obtain a complete overview of their trip to work. The second part of the revealed preference pilot investigates attitudes towards shared bicycles and reasons why commuters use them or not. For this part of the survey, attitudes will be coupled with travel behaviour and possible system changes. It gives a comprehensive overview of when public transport and shared bicycles will be used and builds on the literature in exploring what factors assist in enhancing the usage of this multimodal combination.

Ethical concerns

It is important to be selective and cautious in data collection. Since a survey is a way to investigate human behaviour and opinions, it is important to oblige privacy-related guidelines. In cooperation with the TU Delft data stewards and the HREC committee which concerns human ethics for research, a data management plan is created and approved in which the survey proposal is discussed. Furthermore, in the survey, it is possible to decline to answer socio-demographics if the respondent does not want to give that information. For the origin and the destination of the commuting trip, no more than a PC-5 (Postal code up to 5 of 6 numbers) is required to maintain the privacy of the respondents.

3.1.2. Stated preference experiment

In addition to revealed preference data obtained from the first part of the survey, it is also beneficial to gain insight into the willingness of commuters to shift from car to public transport if certain changes in the bicycle sharing system, infrastructure and policies are implemented. For the survey, respondents will be presented with several choice situations. Within these situations, the respondent can opt for one of the choices with varying attribute levels. The number of choice sets, alternatives and attribute levels depends on the literature and the choice set design. The choice sets will be created with Ngene, a software that translates utility functions in choice sets. By asking the respondents to select their preferred travel option from these choice options, trade-offs can be made between different system attributes to identify what elements can influence the decision-making process for commuting trips.

The interaction between the respondent's choices, sociodemographics and other travel characteristics is examined to identify relations between these attributes and the willingness to adopt shared bicycles within their commuting trips.

3.1.3. Discrete choice modelling

Integrated within many transportation studies is discrete choice modelling to assess mode choice behaviour (Haghani et al., 2021). A discrete choice model is applied to convert the data retrieved from the stated choice element of the survey to interpretable conclusions on mode choice. Discrete choice models are used to assess the mode choice for active modes (e.g. Ton et al., 2019, Barbour et al., 2019, Campbell et al., 2016), to assess passenger preferences for emerging modes on first and last mile (Torabi et al., 2022, Fan et al., 2019) and destination choice preference for bicycle sharing (Faghih-Imani and Eluru, 2015).

For this study, a multinomial logit (MNL) model is applied to the data to interpret the stated preference experiment. A mixed logit (ML) was also considered to capture heterogeneity among the public transport alternatives. However, the sample size in this study is relatively small with 105 respondents. Rainly and McCaskey (2021) suggest that a sample size of 500 is sufficient to capture the increasing complexity of mixed logit while maintaining descriptive power. Hence, a multinomial logit (MNL) model is applied to tackle data limitations and to keep interpretability and efficiency, while also being efficient in computational power requirements (van Cranenburgh, 2023). A multinomial logit model calculates the probabilities of an alternative *i* being chosen and estimates the parameters β according to these probabilities and the final choices made by the respondent. The MNL model uses Equation 3.1 for the probabilities (Ambo et al., 2021):

$$P_j = \frac{\exp(\sum x_{ij}\beta_{ij} + \epsilon_j)}{\sum_{j=1}^{J} \exp(\sum x_{ij}\beta_{ij} + \epsilon_j)}, \quad j = 1, 2, \ldots, J \tag{3.1}$$

Where:
P_j: The probability of alternative *j* being chosen.
x_{ij}: The attribute level for attribute *i* for alternative *j*
β_{ij}: The beta value for attribute *i* for alternative *j*
ϵ_j: The standard error for alternative *j*

In this equation, the sum of the attribute levels times the β values equal the utility V_j for the alternative j. Both the β values and attribute levels for the base MNL model are identified beforehand and used in the stated choice experiment. The attribute and their corresponding values are explained in more depth in Chapter 4.

First, to estimate the model, including the fit of the model, the Biogeme package is used in Python (Bierlare, 2003). With the help of this tool, a base model is estimated, where the corresponding model quality will be determined.

Second, based on this model, interaction effects with sociodemographic attributes are obtained for further specification and improvement of the model quality. These interaction effects are also introduced in Montes et al. (2023) to improve and specify the base model on mode choice and its representation in the model is shown in Equation 3.2.

$$U_i = ASC_i + \sum_j \beta_{ji} \times x_{ji} + \sum_k \sum_j \beta_{kji} \times x_{ji} \times D_k \tag{3.2}$$

Where:
β_{kji} implies the interaction parameter for alternative *i*, parameter *j* and socio-demographic category *k*.
x_{ji} implies the attribute level for alternative *i* and parameter *j*.
D_k implies the dummy variable indicating that the respondent is in a demographic group *k*.

Identifying interaction effects is necessary to determine the sensitivity of specific demographic groups with the parameters of the base model. Interaction effects are initially tested individually. If these parameters show insignificant ($P > 0.05$) interactions without other interaction parameters in the model, they are not included in the model with the base model + the significant interaction effects. Before optimisation, similar behaving sociodemographic groups are identified and merged to optimise the addition of demographic interaction effects in the model. Two demographic groups are considered similar in behaviour if the chi-squared test statistic of the two groups does not exceed the threshold value. Equations 3.3 through 3.5 show how this chi-squared statistic is calculated.

$$\chi^2 = \sum_{i=1}^{n} \frac{(O_i - E_i)^2}{E_i} \tag{3.3}$$

with:
χ^2: The Chi-squared test statistic.
O_i: The observed choice frequency for the i-th category.
E_i: The expected choice frequency for the i-th category.
n: The total number of categories.

Where the expected value for a cell is calculated as:

$$E_i = \frac{(R_i \times C_i)}{N} \tag{3.4}$$

with:
R_i: The sum of the choice frequencies per sociodemographic category.
C_i: The sum of a single choice frequency i among all sociodemographic categories.

The threshold for assessing similarity is determined by calculating the degrees of freedom within the test using the following formula.

$$(R_i - 1) \times (C_i - 1) \tag{3.5}$$

Again, R and C represent the number of rows and columns.

This revised demographic categorisation is now applied to account for the effect of sociodemographics and current travel preferences on the decision-making process.
Finally, with backward elimination, assessing the significance of the parameters when combined with the other interaction effects, the model fit, and the correlation, a final model is constructed that describes what factors influence the mode choice for the alternatives in the stated choice experiment and what role sociodemographic play in mode choice. A backward elimination process denotes the final step of the model optimisation and is characterised by a stepwise elimination of interaction parameters based on the level of insignificance. In each step, the interaction parameter with the highest p-value is eliminated. This process starts with the base model and individually significant interaction parameters merged into a single model. A final MNL model will be obtained by iteratively assessing the quality of the model and removing parameters until a significant model is established (All interaction parameters have a p-value of below 0.05).

3.1.4. Model application

To link the model output to real-world applications. Two analysis methods are initiated. The model is initially used in a simulation in which the model parameters (β), utility functions (U_i) and sociodemographics of the residents of South Holland are used to simulate the decision-making process for the mode choice. Paragraph 3.1.5 introduces the study area on which this analysis is performed, serving as the two example trips. A persona-based simulation is added to gain more in-depth insight into the interaction effects between sociodemographics and mode choice. In both analyses, the adjustments of the shared bicycle system are tested to determine the marginal effect on the modal split. For this simulation, demographic data from South Holland is used to mimic the demographics of commuters. This method is applied to optimise the reality of the output from the model application. Figure 3.2 schematises the simulation process to clarify how the plots and data within this section are calculated.

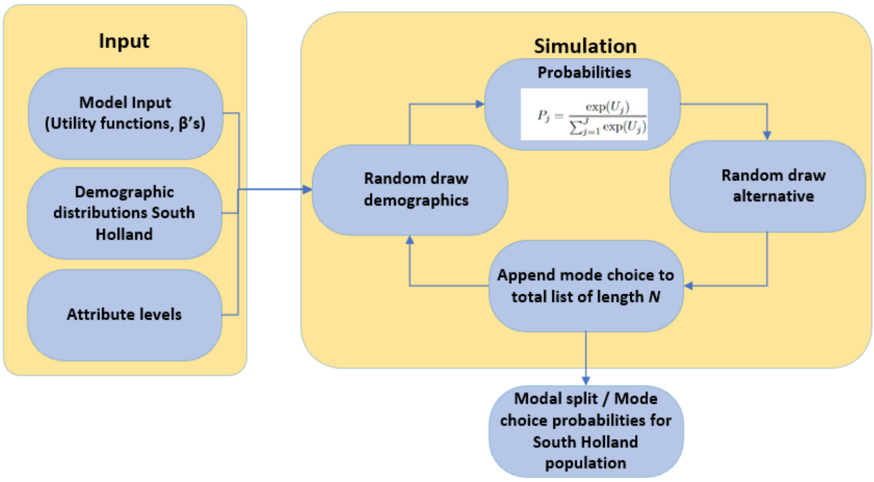


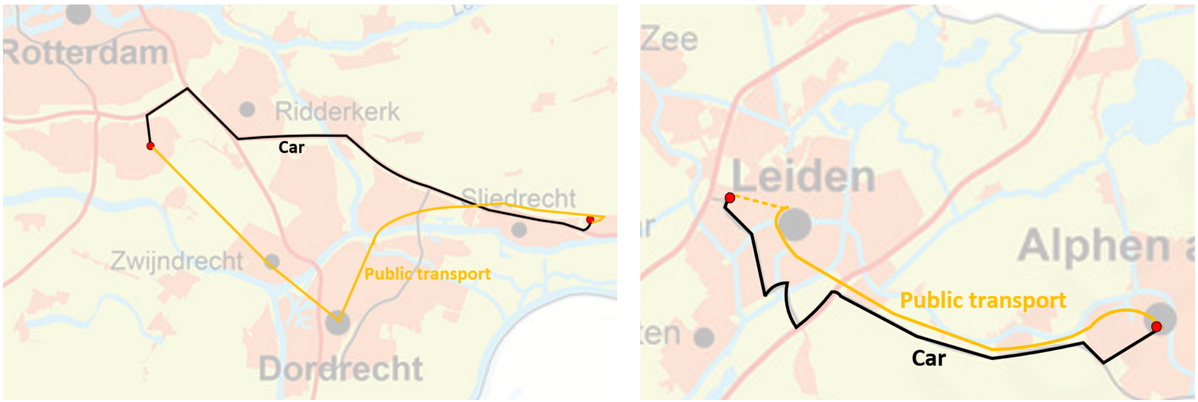
Figure 3.2: Simulation process for model application on case studies

3.1.5. Study area

The study area to examine suburban behaviour is scoped to the province of South Holland (As shown in Figure 3.3). South Holland is a fast-growing province in the western part of The Netherlands with around 3.5 million residents. The province is prone to quick suburbanisation where 25 % of the province's land mass is built up with mainly car-oriented neighbourhoods (Provincie Zuid-Holland, 2020), making South Holland a suitable case study area for studying suburban commuting behaviour.

Figure 3.3: Study area South-Holland in perspective (Kaart van Den Haag, n.d.)

This scope is translated in two ways: Data collection focus and application. The data collection focus on South Holland is further elaborated on in Section 3.1.6. For the application in suburban areas in South Holland, two case studies are introduced to convert the results of the stated preference survey into a more practical and comprehensive analysis. This research aims to understand suburban commuter behaviour and will optimise the implementation of bicycle sharing in South Holland. The two case studies relate to two study areas where Provincie Zuid-Holland is currently investigating shared bicycle potential, Leiden and Drechtsteden. They monitor behaviour via a pilot with the Donkey Republic bicycle sharing system. Two example routes shown in Figures 3.4a and 3.4b will apply the output of the stated choice model to investigate more in-depth how shared bicycle optimisation and car discouraging measurements enhance public transport and shared bicycle usage. These two routes also have the possibility for a Donkey Republic shared bicycle which aids in investigating the possibilities for this type of bicycle sharing. Furthermore, these routes are chosen based on a travel time of around 20 to 30 minutes, complying to the hypothetical scenarios in the stated preference experiment,the suburban study area, and the home-end locations are on a walkable distance from a train station.



(a) Example route Drechtsteden

(b) Example route Leiden

Figure 3.4: Comparison of example routes

3.1.6. Data collection

The survey targets commuters to suburban areas, with South Holland as the case study. Key focus areas include Leiden, Katwijk, Oegstgeest, and the Drechtsteden. This paragraph elaborates on how this target group is optimally addressed to aim for maximal representativeness within the dataset.

The data-collection process for survey respondents consists of multiple parallel methods to obtain a sufficient response rate. Initially, the survey is distributed to the right audience via LinkedIn, with professors and colleagues reposting it to optimise the response rate and reach the target audience. In addition to LinkedIn, Facebook groups are addressed, consisting of people who meet the criteria of the target group. Moreover, various mobility managers via Provincie Zuid-Holland, municipalities and company managers are targeted to distribute the survey among larger groups of companies and municipalities. Most companies contracted through Provincie Zuid-Holland are located within one of the study areas, as described in Section 3.1.5 to make the response group optimally align with the target group and thus the scope of this research.

4 Survey

This chapter translates the key influencing factors identified in the literature study into a structured survey design. Chapter 4.1 discusses the design in more detail, breaking down the structure and interconnection of the parts of the survey. Chapter 4.2 elaborates further on the revealed preference, explaining the conceptual framework and attributes in more detail. This analysis will expand the literature on the following sub-question:

Sub-question 2 - What elements influence the usage of shared bicycle systems?

Moreover, Chapter 4.3 describes the design of the stated preference experiment, the assumed attributes, and the assumptions. This part of the survey will dive into quantification of the choice behaviour and will answer the following sub-question:

Sub-question 3 - To what extent will commuters change their travel patterns and mode choices in response to changes in bicycle-sharing infrastructure, public transport and measures discouraging car use?

4.1. Survey design

The survey is structured into three parts: Revealed preference, Stated preference and Sociodemographics. These sections contribute collectively to the analysis of commuter behaviour, attitudes and preferences towards shared bicycles integrated with public transport.

The first part of the survey discussed the revealed preference which investigates current travel behaviour and attitude and knowledge towards shared bicycles. This part is divided in two subsections: Current commuter behaviour identification and specific attitude and knowledge about bicycle-sharing systems. This part is further discussed in Chapter 4.2.

The second part of the survey consists of a stated preference analysis that evaluates hypothetical scenarios to identify and quantify commuters' behaviour and their trade-offs during mode choice. The design and considerations of this experiment are discussed in Chapter 4.3.

The survey concludes with questions regarding sociodemographic of the respondents. This part identifies the demographic data which can be further analysed to identify relations between demographic data and travel and choice behaviour. The structure of the survey and the order in which the respondents see the questions are clarified in Figure 4.1.

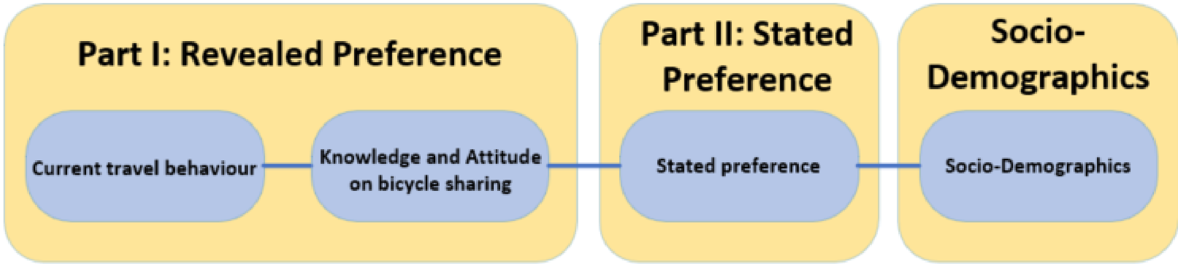


Figure 4.1: Survey structure flowchart

4.2. Part I: Revealed preference survey

The revealed preference part of the survey will evaluate respondents' current travel behaviour and how they regard the usage of shared bicycles in their journey from home to work. It also discovers the relationship between travel behaviour and attitude towards shared bicycles. The survey opts to investigate attributes that align with the key literature findings from Chapter 2 by asking the respondents about attitudes towards shared bicycles and guiding them with answering multiple-choice questions to identify which attributes do and do not enhance shared bicycle usage and under what conditions.

4.2.1. Attributes

The attributes adopted in the revealed and stated preference parts are categorised and schematised as in Figure 4.2. The behavioural model identifies three main categories that impact the modal shift or modal share for public transport and shared bicycles. The first is the preference for shared bicycles, depending on the attributes of the shared bicycle system. This category is divided into physical/infrastructural attributes and non-physical/perception attributes.
Second, attributes related to the public transport + shared bicycle combination are considered. Third, the attributes related to the commute by car are implemented in the model. For all three of the categories, sociodemographics influence the choice behaviour of the mode choice and is thus schematised as an overarching attribute category in the simplified model.

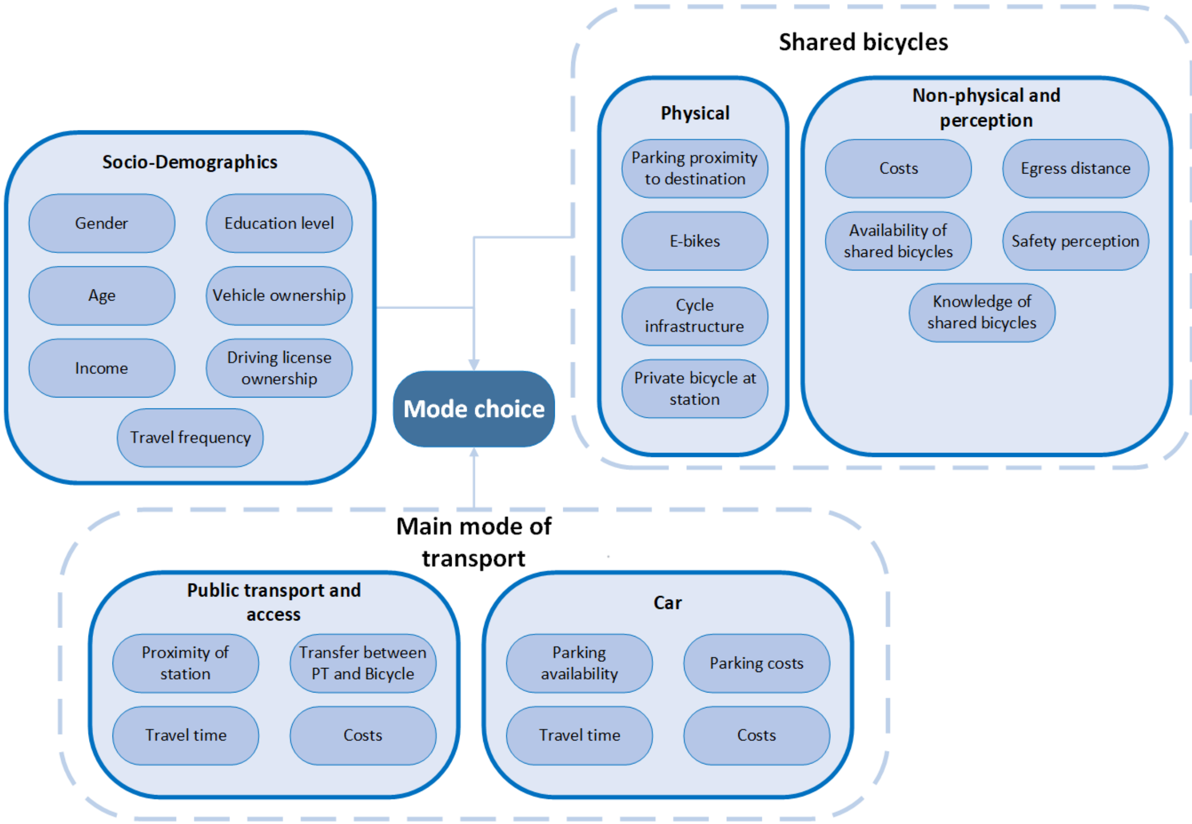


Figure 4.2: Conceptual framework for survey

The literature study in Chapter 2 and the conceptual framework in 4.2 show that shared bicycle usage in combination with public transport depends on various variables. A large scale of behavioural, infrastructural, and demographic attributes play a role in the mode choice of commuters. Capturing the entire range of elements that might affect this choice behaviour is almost impossible in a concise survey (around 10 minutes). Therefore, a selected set of attributes is integrated to map current behaviour and attitude optimally. This paragraph analyses which attributes related to shared bicycles, cars and public transport are adopted in the survey and how these attributes will help describe travel behaviour.

The attributes related to shared bicycles are crucial for understanding the influence of their usage. Costs, travel time, and the egress distance between the station and work location are particularly significant, as they directly affect commuters' willingness to adopt shared bicycles (e.g. Adnan et al., 2019; Ton et al., 2019; Bachand-Marleau et al., 2012). The survey assesses how modifications in these areas, such as reduced rental costs or improved availability of shared bikes, impact the choices of suburban commuters. Recognising that the availability of shared bicycles affects usage rates, the survey explicitly addresses this issue to uncover its effect on adoption rates (Brand et al., 2017; Fan et al., 2019). The survey also tackles the quality and perception of the safety of the bicycle infrastructure around stations (Fishman et al., 2012; Leth et al., 2017). Moreover, the survey explores the effect of private bicycles as literature uncovered that this attribute affects the potential for shared bicycles (Krizek, 2011). Additionally, the lack of technical knowledge regarding bicycle rentals is included in the survey to determine whether this creates a barrier for potential users (Jorritsma et al., 2021). The inclusion of e-bicycles as a distinct attribute is also worth mentioning, as the literature indicates their potential to mitigate the challenges posed by longer egress distances (Campbell et al., 2016).

Turning to car commuting, travel time, parking availability, and the cost of parking at work are included in the survey. Understanding these factors is essential, as the literature concluded that these attributes discourage car commuting (Ton et al., 2019; Buehler, 2012). Hence, possibly benefitting public transport and shared bicycles. The survey asks respondents how changes in parking policy, such as increased costs or reduced availability, might influence their choice to switch to public transport or shared bicycles.

For public transport and first-mile integration, attributes related to travel time and the efficiency of transferring between public transport and shared bicycles are examined (Ton et al., 2019; Ma et al., 2020). The survey investigates the respondents' perceptions of these transfer processes and their influence on mode choice. Proximity to public transport stations is also included in the survey. By systematically addressing these attributes, the study aims to comprehensively analyse the interactions between shared bicycles and public transport and to understand how these factors affect commuting behaviour in suburban areas.

Table 4.1 and Table 4.2 summarise the shared bike and car-related attributes in the survey, as informed by the literature. These tables also indicate how frequently attributes are included in the survey by indicating the number of questions that mention the attribute.

Table 4.1: Survey attributes: Shared bicycle

Attribute	Number of questions
Costs	3
Travel time	2
Availability and security of available bicycles	2
Distance	1
Bicycle infrastructure quality	1
Perception of safety	1
Private bicycle at the train station	1
Knowledge of shared bicycle	1
Implementation of E-bicycles	1

Table 4.2: Survey attributes: Car

Attribute	Number of questions
Parking at work	3
Free parking at work	2
Travel time	1

Table 4.3: Survey attributes: Public transport and first-mile

Attribute	Number of questions
Transfer between PT and Bicycle	2
Proximity of a PT station	1
Travel time for PT	1

4.2.2. Socio-demographics

Most of the socio-demographics retrieved from the literature study in Chapter 2 are integrated into this survey design. It is valuable to know the difference in travel behaviour given different demographics and if this might vary between suburban areas and urban areas. Also, the socio-demographic influence on mode choice is worth studying for the stated choice model, as shown in relevant related studies using stated choice modelling. Table 4.4 shows the adopted socio-demographics for this research.

Table 4.4: Survey attributes: Sociodemographics

Attribute	Attribute type
Age	Categorical
gender	Categorical
Education level	Categorical
Income	Categorical
Availability of a driving licence	Dummy
Car ownership	Dummy
Travel frequency	Categorical

The above-mentioned socio-demographics are coded and implemented in the following way: Age is separated into categories for age groups from 18 years and older since the focus is on commuters using the car. For gender, Inclusiveness is incorporated in the answer options including an opt-out if people do not want to answer this question. Travel frequency is expressed in the number of times someone commutes per week. The socio-demographic categories are based on a mix of academic references and arbitrary categorisation. So are gender, age, education and income mentioned in various studies (Geržinič et al., 2023; Ton et al., 2019; van Marsbergen et al., 2022; Montes et al., 2023). These studies include education as "high school, MBO, bachelor, master" or "low, medium, or high". For this study, high school, MBO, HBO and University are chosen as arbitrary but literature-sustained categories. Age and income groups show quite varying categorisations in the literature. Therefore, arbitrary categories are chosen where the mean category complies with the mean income level of Dutch residents. For age categories, it is still possible to make a comparison with the South Holland population. Commuting frequency is arbitrarily chosen based on a full-time workweek (5 days) as the highest category and 0-1 time per week as the lowest. All categorical parameters, thus excluding the dummy variables car and licence ownership, are summarised in Table 4.5 and constructed in the survey as such:

Table 4.5: Socio-demographic categories

Socio-demographic	Category
Age	18 -
	18 - 30
	30 - 45
	45 - 60
	60 +
Gender	Male
	Female
	Non-Binary / other
	Rather not say
Income	€0 - €20.000
	€20.000 - €30.000
	€30.000 - €45.000
	€45.000 - €60.000
	€60.000 - €80.000
	€80.000 +
	Rather not say
Education	Primary school or high school
	MBO
	HBO
	WO
	Rather not say
Travel frequency	0 to 1 times
	2 times
	3 times
	4 times
	more than 5 times

4.3. Part II: Stated preference survey

This section describes the stated preference part of the survey to assess hypothetical scenarios that cannot be identified with the revealed preference part. Since a revealed preference study does not fully identify trade-offs between alternatives or reveal how specific attributes influence mode choice, given the limited insight into alternatives not chosen by respondents, a stated preference experiment is included to explore this gap.

4.3.1. Model attributes and attribute levels

For the stated preference part of the survey, attributes are considered that are generally not yet implemented in the two case-study areas Leiden and Drechtsteden. Considering the case study areas, the 4 most suitable alternatives are considered for a trip that is not possible to do by bicycle or is unrealistic to be done by bicycle. Considered are thus the car, public transport combined with a shared bicycle as a last-mile mode, public transport where the shared bicycle is electric and an option where just public transport is used. This last option is simplified to a train trip where the last mile is served by bus.

Travel time

The travel time is an important attribute when analysing mode choice (Ton et al., 2019). For this research, a simplified stated preference is initiated where the total travel time alternative varies between 20 and 40 minutes and is split up into the last-mile travel time and the travel time of the main journey + access time if applicable. Assessing travel time and last-mile travel time indicates the value of travel time for the main mode of transport and for the egress mode (Shared bicycle, shared e-bicycle and bus).

Rental costs shared (e)-bicycles

According to Adnan et al. (2019) and Montes et al. (2023), rental costs of a shared bicycle enhance the usage rates of this egress mode and thereby the usage rates of public transport + shared bicycle for commuting trips. Together with the travel time and the egress travel time, trade-offs can now be identified between the rental costs and travel time.

Parking costs car

An attribute more related to discouraging travelling by car is the parking costs at work. Introducing a small varying fee could encourage people to switch to public transport. Furthermore, by introducing this attribute, comparisons with the rental shared bicycle costs can be made to identify which attribute affects the mode choice more significantly.

Parking availability and distance from hub to work

To incorporate the effect of parking availability for cars and shared bicycles (Buehler, 2012; Currie and Delbosc, 2011) a search time attribute for a parking spot at the work address is added to schematize the availability of car parking at the location. For bicycle parking, it is defined as the walking time from the nearest bicycle hub to the office. This reflects the local context, as Donkey Republic bicycles, for instance, can typically only be docked at designated stations, often located near office clusters. To account for varying distances from the hub to the office, the model incorporates walking time as an attribute.

Type of bicycle membership

Donkey Republic, the bicycle-sharing company that operates in the study areas, offers a different type of membership or type of shared bicycle system than the NS OV-fiets. The OV-fiets is a shared bicycle that functions as a back-to-one system where the traveller rents a bike that can be rented for 24 hours before paying an extra fee. Furthermore, the bicycle is always owned by the traveller for that period. The Donkey bicycle can be driven from docking station to docking station across the area and is thus only in possession between the two hubs. This research will also investigate if people benefit from one system over the other and if they are willing to pay more for one of the two. Therefore single ride or 24-hour possession are included in the survey.

Table 4.6 summarises the attributes and displays the attribute levels used in the stated preference experiment. The total travel time for commuting trips (Travel time car and travel time + travel time egress) is based on the average commuting time in 2023 (Centraal Bureau voor de Statistiek, 2024c), which varied between 27 and 35 minutes for commuters of over 18 years old. To ensure a dominant alternative to not occur, the total travel time for car and public transport + egress is kept comparable, with some travel time removed from the E-bicycle alternative. The egress times are based on an egress distance of 1.5 to 3 kilometres with 15 km/h cycling speed. The other time and cost attributes are chosen arbitrarily, such that they are realistic and do not create a dominant attribute.

Table 4.6: Attributes stated preference experiment

Attribute	Attribute levels
Travel time Car	20 minutes 30 minutes 40 minutes
Travel time public transport	14 minutes 21 minutes 28 minutes
Egress travel time	6 minutes 9 minutes 12 minutes
Egress travel time e-bike	3 minutes 6 minutes 9 minutes
Rental costs Shared bicycle	€ 0 € 3 € 6
Parking costs	€ 2 € 4 € 6
Parking search time car	1 minute 3 minutes 5 minutes
Walking time hub to work	1 minute 3 minutes 5 minutes
Type of shared bicycle system	Single ride 24-hour membership

4.3.2. Context variables

Context variables are predefined variables that describe the setting that respondents must assume when making choices. It tells the physical, and socio-emotional setting in which behaviour occurs (Molin, 2024a). For this choice experiment, it is important to assume the travel context in which people commute. Respondents are instructed to assume **dry weather and the temperature is comfortable** for cycling, as rain negatively affects the willingness to cycle (Corcoran et al., 2014).

Furthermore, the respondent should assume that public transport and the car are **subsidised by the employer** and that the only extra costs are the shared bicycle and the parking costs. To link the stated preference survey to revealed data from the first part of the survey, **the travel frequency** to work is assumed as a context variable for the choice sets. By introducing this relation, the model accounts for the influence of travel frequency on mode choice and determines if more frequent travellers are willing to adopt shared bicycles more often than less frequent travellers.
Finally, The trip from home to work is assumed to be impossible by only a bicycle or walking. Considering this assumption, the four alternatives are the only possibilities for this journey so no opt-out alternative is necessary.

4.3.3. Choice sets survey

This section will elaborate on how these sought-after attribute effects can be captured in a model. Based on this model, the survey design of the stated choice part can be designed.

Model

The corresponding model is constructed in Ngene, a software for stated preference analyses. Equations 4.1 through 4.4 show the initial utility functions designed for this experiment :

$$U_{car} = \beta_{tt_{car}} \cdot tt_{car} + \beta_{t_{parking}} \cdot t_{parking} + \beta_{c_{parking}} \cdot c_{parking} \tag{4.1}$$

$$U_{PT+SB} = ASC_{PT} + ASC_{shared\ bicycle} + \beta_{tt_{PT}} \cdot tt_{PT} + \beta_{tt_{egress}} \cdot tt_{egress} + \beta_{c_{SB}} \cdot c_{SB} + \beta_{tt_{walk\ hub\ to\ work}} \cdot tt_{walk\ hub\ to\ work} + \beta_{system} \cdot system \tag{4.2}$$

$$U_{PT+Electric-SB} = ASC_{PT} + ASC_{shared\ bicycle} + \beta_{tt_{PT}} \cdot tt_{PT} + \beta_{tt_{egress}} \cdot tt_{egress} + \beta_{c_{SB}} \cdot c_{SB} + \beta_{tt_{walk\ hub\ to\ work}} \cdot tt_{walk\ hub\ to\ work} + \beta_{system} \cdot system \tag{4.3}$$

$$U_{PT} = ASC_{PT} + \beta_{tt_{PT}} \cdot tt_{PT} + \beta_{tt_{egress}} \cdot tt_{egress} + \beta_{tt_{walk\ hub\ to\ work}} \cdot tt_{walk\ hub\ to\ work} \tag{4.4}$$

Where:

$tt_{car} =$	Travel time by car
$t_{parking} =$	Time to find a parking spot by car
$c_{parking} =$	Parking costs
$tt_{PT} =$	Travel time in public transport
$tt_{egress} =$	Egress travel time by shared bicycle
$tt_{walk\ hub\ to\ work} =$	Travel time from bicycle parking/hub to work
$c_{SB} =$	Rental costs for the shared bicycle
$system =$	Dummy variable indicating the type of shared bicycle system

Based on this design, a set of choice sets has to be constructed to obtain a statistically relevant parameter estimation and also obliges the idea that survey respondents should not answer too many choice situations. Based on these criteria, a D-efficient design minimises the number of choice sets that should be asked for while maintaining this statistical significance. An efficient design is generally preferred over an orthogonal design to ensure more information about trade-offs can be obtained, minimise the number of choice sets and optimise the parameter reliability (Molin, 2024b). According to Molin (2024b), D-efficient designs are preferred because they ensure the general reliability of all the parameters in the model. On the contrary, S-efficient designs optimise the reliability of the parameter that needs the most respondents for significance.

4.3.4. Prior parameters

For an efficient design, it is necessary to identify or estimate prior parameter values for the model, Table 4.7 will describe the prior values based on literature that performed stated preference surveys on bicycle sharing. However, the suburban context may not always be the case in the assessed literature, since this is identified as a gap. However, since these priors serve as an estimation for the model, the identified values suffice. The type of shared bicycle system is additional and studied in this research. Since there is no prior knowledge of the magnitude and sign of the prior parameter, this value is treated as 0 (Molin, 2024b). Prior parameters do not influence the outcome of the final model, especially since this model is expanded with sociodemographic interaction effects. Priors are used to create a feasible and optimal D-efficient design, determine how many choice sets are necessary to obtain all significant parameters, and validate that no dominance occurs across the choice alternatives (Molin, 2024b).

Table 4.7: Prior values for β

Attribute	Literature values	Chosen prior
Travel time	-0.05 (Weiss et al., 2011) -0.057(Krauss et al., 2022)	-0.050
Travel time public transport	-0.065(Krauss et al., 2022)	-0.065
Egress travel time	-0.142 (Weiss et al., 2011)	-0.142
Parking availability	-0.04 (Krauss et al., 2022)	-0.040
Parking costs	-0.129 (Weiss et al., 2011)	-0.129
Rental costs	-0.437 (Adnan et al., 2019) -0.425 (Montes et al., 2023)	-0.430
Walking time hub to work	-0.117 (Weiss et al., 2011)	-0.117
Type of system	Not literature based	+0.000

4.3.5. Choice sets and survey design

Validation

Based on the model and the prior parameters, 12 choice sets are generated according to a D-efficient design, as described in paragraph 4.3.3 and are separated into two blocks of 6 to minimise the number of questions per respondent to restrict the survey length. Based on the constructed choice sets, two elements should be validated, the number of respondents needed to reach significance and the presence of dominance in one of the four attributes. Although removing dominance is one of the main benefits of an efficient design, this should still be validated to check whether the alternative levels are realistic and if trade-offs can be made based on the model results.

To check if no dominance occurs, it should be concluded that none of the alternatives in one of the choice sets has an occurrence probability of higher than 90% ($P_i < 0.9$). For the choice set in this study, the highest probability that one alternative is chosen in one of the choice sets is approximately 0.7. Thus, no dominance occurs in this experiment design.

The efficient design uses the predetermined prior parameter values for the number of respondents needed. Ngene determines the minimum number of respondents based on the standard error of the parameter when the number of respondents equals 1. The following formulas apply when calculating the number of respondents to get theoretical statistical significance:

$$t_{N=1} = \frac{\beta}{\sigma} \tag{4.5}$$

$$N > (\frac{1.96}{t_{N=1}})^2 \tag{4.6}$$

In this equation, N is the number of respondents, β the parameter value and σ the standard deviation as calculated by Ngene. For this stated preference experiment, Ngene calculated that the number of respondents should be 225 for the design used in the survey. However, from the 12 choice sets from the efficient design, only 6 are provided equally to the respondents. Therefore, 550 respondents are required to ensure statistical significance of the parameters, assuming the prior values.

Survey design

In Figure 4.3, the choice set is displayed, in which the respondent has to choose the alternative that suits the respondent the most.

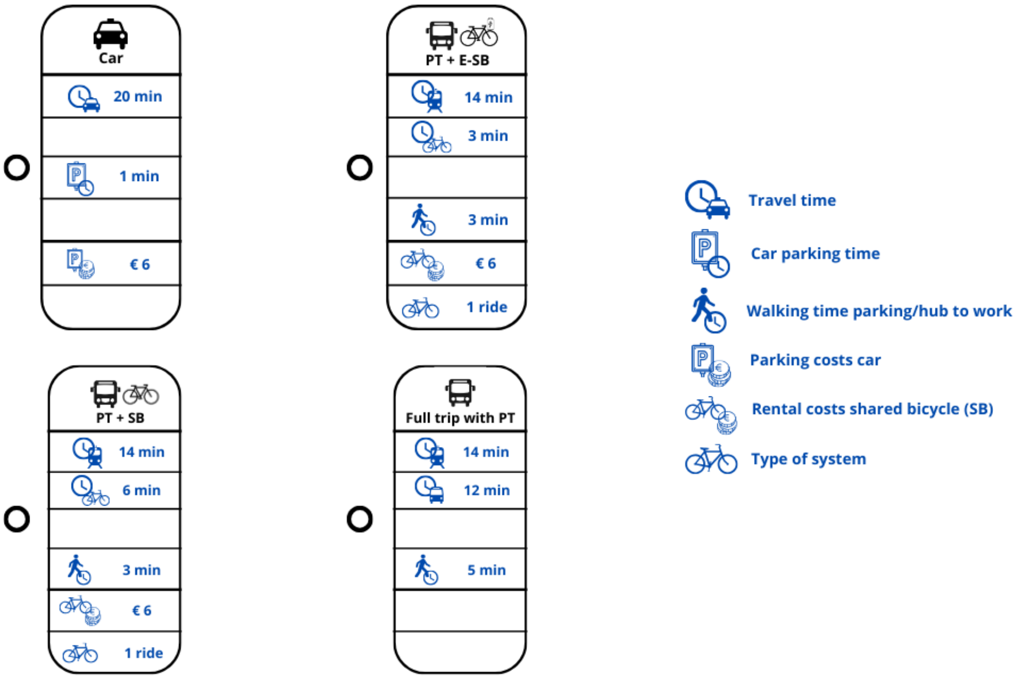


Figure 4.3: Example of a choice set

As visualised, the four alternatives are given as four choice options of which the respondents are shown 6 different combinations. As discussed earlier, these four choice options represent the 4 alternative travel options initiated for the home-to-work trip. Based on the 12 choice sets constructed by Ngene, attributes are assigned to each of the travel alternatives as visible in the design in Figure 4.3. The attribute levels and the corresponding block in which they are presented to the respondent is shown in Appendix C

4.4. Considerations and fine-tuning

4.4.1. Survey optimisation

For the survey to be successful and provide the right, sought-for answers, it is important to consider the following:

- Put demographic-related questions, such as ”What is your age”, at the end of the survey. This is necessary to obtain the more important information related to the research objective early in the survey and to get a sense of direction in the survey where general questions become more personal at the end of the survey
- Manage the survey length. The completion rate of the survey needs to be as high as possible to maximise the value and the statistical significance of the answers. According to Revilla and Ochoa (2017), the optimal length of a survey is 10 minutes or a mean of 12.5 minutes. They also comment that 20 minutes is considered the maximum acceptable survey length. The survey attempts to stay around 10 to 12 minutes to optimise the response rate.

Pilot

To test the duration and quality of the survey, it was distributed to colleagues and peer students ($N = 10$). It concludes that the survey duration was approximately 11 minutes with outliers on both sides (6 minutes to the lower bound and 15 minutes to the upper bound). After fine-tuning and further verification of the quality and length of the survey. This duration was considered acceptable and was between the limits found in the studies. This pilot mainly highlighted grammar and spelling mistakes that were fixed iteratively during the pilot period, but also some questions and statements that were unclear to the respondents were underscored and clarified in the survey.

5

Results of revealed preference

This chapter discusses the findings from the revealed preference section of the survey. Chapter 5.1 describes the dataset obtained from the survey and shows the sociodemographic distribution. Chapter 5.2 examines current travel behaviour, the integration of shared bicycles into commuting routines, and the potential of shared bicycles for last-mile trips in a suburban context based on attitudes toward them. Chapter 5.3 summarises the findings to give a concise overview of this chapter. This chapter expands the findings of the literature to the following sub-question:

Sub-question 2 - What elements influence the usage of shared bicycle systems?

5.1. Data filtering and Socio-Demographics

5.1.1. Data filtering and dataset statistics

The survey ultimately obtained 132 respondents who started the survey. From this set of participants, 105 of the 132 respondents completed the survey (The column in the dataset indicating the survey completion returned true). To further assess the quality of the answers, a minimum completion time threshold of 3 minutes or 180 seconds is set to remove quickly given responses deemed less valid. In this research, all 105 remaining responses had a completion time of over 180 seconds, resulting in a final dataset for analysis of 105 respondents. However, the prior parameter analysis pointed out that 550 respondents are minimal for statistical significance. The study thus uses 5 times fewer respondents as suggested by the Ngene design. However, 105 respondents (630 data points out of 6 choice sets per respondent) still managed to showcase sensible results.

The median completion time of the survey is 9.3 minutes and the mean completion time is 54.9 minutes. There are two explainable reasons why the mean value is disproportional to the median and the expected duration of around 10 minutes. Due to the lower amount of responses, outliers affect mean values more than with larger samples. Since Qualtrics gives the option to stop and resume the survey somewhere within two weeks after the starting date, the maximum value for the duration is 3783 minutes or 2.6 days. When only regarding responses with a duration of less than 1 hour, the mean duration is just 11.1 minutes, showing the effect of the outliers well. Figure 5.1 shows a distribution of the completion time under 60 minutes, where the more realistic mean and median values of around 10 minutes are clearly shown.

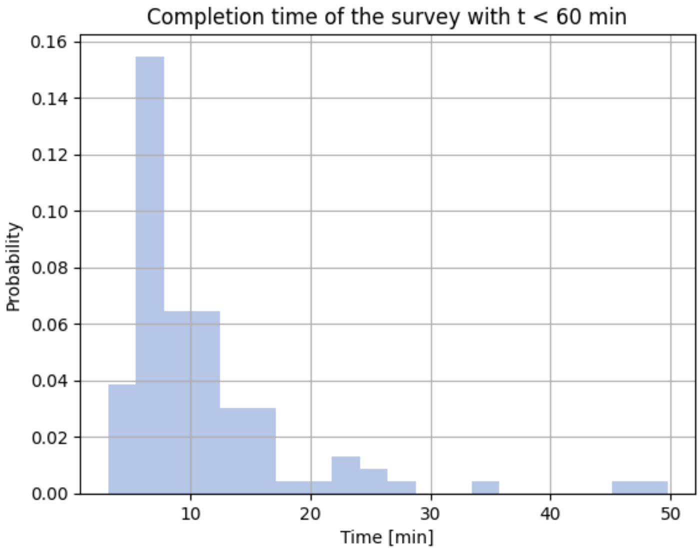


Figure 5.1: Completion time distribution for the survey

5.1.2. Socio-demographics

This section covers the descriptive statistics of the dataset obtained from the survey results. To identify the representativeness of the dataset, the demographic data for inhabitants of South Holland is gathered and compared with the dataset in Table 5.1.

Table 5.1: Socio-demographics from the respondents and average South Holland

Demographic	Category	Abs. number	Percentage	Percentage SH [2]	$\Delta\%$
Age[1]	18 -	0	0.0 %	0.0 %	+0.0
	18 - 30	52	49.5 %	19.9 %	+29.6
	30 - 45	13	12.4 %	24.8 %	-12.4
	45 - 60	32	30.5 %	24.1 %	+6.4
	60 +	8	7.6 %	31.2 %	-25.6
Gender	Male	58	55.2 %	49.1 %	+6.1
	Female	47	44.8 %	50.9 %	-6.1
	Non-Binary / other	0	0.0 %	0.0 %	+0.0
	Rather not say	0	0.0 %	0.0 %	+0.0
Income	€0 - €20.000	24	22.9 %	27.9 %	-5.0
	€20.000 - €30.000	7	6.7 %	21.3 %	-14.6
	€30.000 - €45.000	22	21.0 %	22.4 %	-2.4
	€45.000 - €60.000	12	11.4 %	14.7 %	-3.3
	€60.000 - €80.000	8	7.6 %	9.5 %	-1.9
	€80.000 +	19	18.1 %	4.2 %	+13.9
	Rather not say	13	12.4 %	0.0 %	+12.4
Drivers licence	Yes	101	96.2 %	74.9 %	21.3
	No	4	3.8 %	25.1 %	-21.3
Car possession	Yes	70	66.7 %	53.0 %	+13.7
	No	35	33.3 %	47.0 %	-13.7
Education	Primary school or high school	3	2.8 %	20.0 %	-17.2
	MBO	12	11.1 %	39.0 %	-27.9
	HBO	31	28.7 %	25.0 %	+3.7
	WO	59	54.6 %	16.0 %	+38.6
	Rather not say	0	0.0 %	0.0 %	+0.0
Travel frequency to work	0 to 1 times	6	5.7 %	19.0 %	-13.3
	2 times	21	20.0 %	14.2 %	+5.8
	3 times	27	25.7 %	15.9 %	+9.8
	4 times	27	25.7 %	17.9 %	+7.8
	more than 5 times	24	22.9 %	33.0 %	-10.1

[1] The category ”18- ” was intended to capture respondents under 18 but was not applicable in this study, hence the value is 0.

[2] Data sources for demographic data: Age and gender (Centraal Bureau voor de Statistiek, 2024a), income (Centraal Bureau voor de Statistiek, 2024b), drivers licence (Centraal Bureau voor de Statistiek, 2024e), car possession (Provincie Zuid-Holland, 2024a), education (Sociaal en Cultureel Planbureau, 2020) and travel frequency (Kromhout and Souren, 2024; voor de Statistiek, 2024)

Analysis of demographics

The comparison with demographics within South Holland reveals various biases in the obtained dataset. Noteworthy is that the dataset for this study shows a relatively young population with a higher education level. The share of respondents obtained via the university network might explain this bias in the dataset. The high share of driving licence ownership leads to a hard explainability of the effect of this demographic on choice behaviour ($N_{No\ licence} = 4$). However, since this study aims to investigate the potential for shared bicycles as an alternative of car commuting, the removal of this factor should not affect the outcome of this research much. On the other demographics, much less bias is found between the study dataset and the demographic distribution of South Holland. Among the income groups, a slight skew towards higher income groups is found in the survey data. A grounded explanation for this skew in the data is hard to determine since there is quite some diversity in the companies these respondents work. However, within this group, there is a reasonable share of municipalities and ministries accessed via the Province of South Holland, which might explain the skew a little.

5.2. Travel behaviour

This section covers travel behaviour, knowledge and attitude towards public transport and shared bicycles. These attitudes provide valuable insights into what and what not to consider when implementing bicycle sharing for commuting purposes. Furthermore, the revealed travel patterns of the respondents will be coupled with the trip data and the attitude to determine patterns and correlations between them. The answers are freely translated from Dutch to English. Appendix B shows the original Dutch answer options.

5.2.1. Revealed mobility patterns

This paragraph covers the revealed travel patterns of the respondents given their main modality and their access and egress modes. This paragraph will elaborate on the effect of socio-demographics and (shared bicycle) attributes on the way people currently commute. Figure 5.2 visualises the modalities.

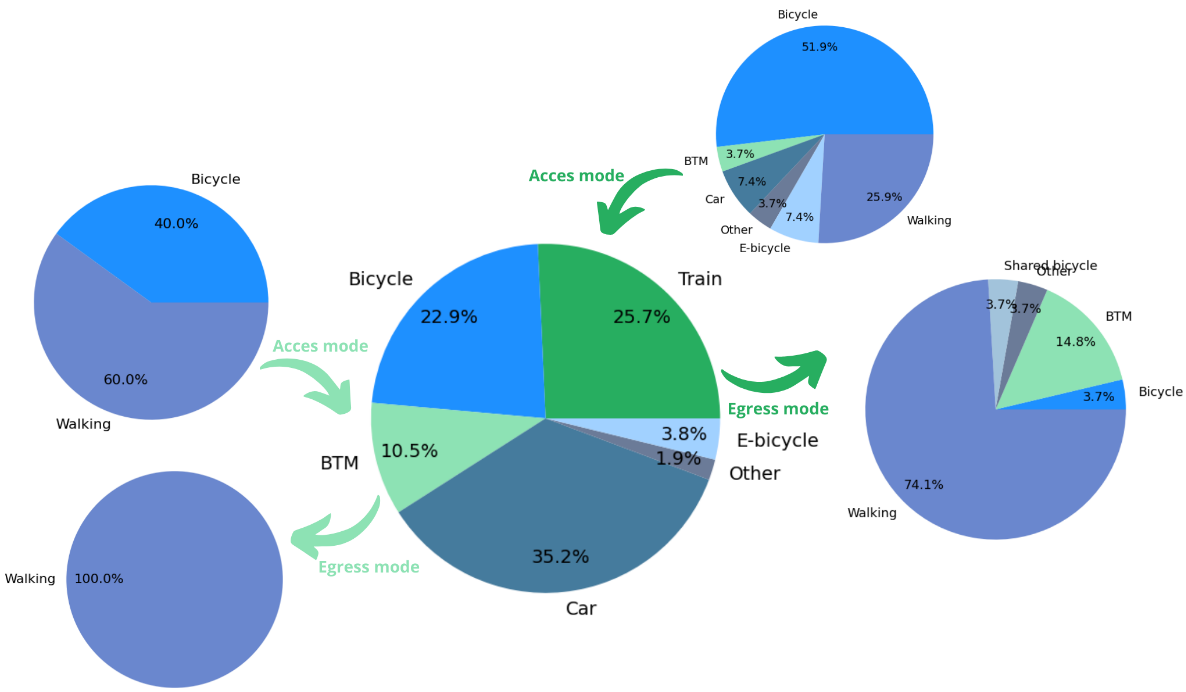


Figure 5.2: Modal split of the respondents

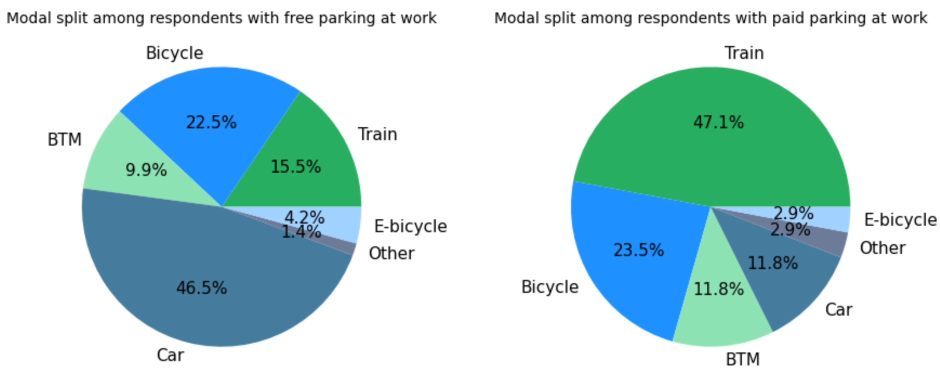


Figure 5.3: Effect of paid parking on modal split

- From the revealed travel data a clear statement is made regarding the effect of paid parking at work.

For the respondents that have to pay for car parking, as shown in Figure 5.3 the modal split for cars was 11.8 % compared to 46.5 % when parking was free, whereas the split for trains was 47.1 % compared to 15.5 %. Considering the trips made by bicycle, this percentage was unaffected by this matter. This can imply that the trips made by bicycle are from such short distances that train and car are less of an option and the effect of paid parking can be neglected.

Effect of socio-demographics on revealed modality

A few conclusions can be drawn regarding the effect of socio-demographics on the main modality of the respondents, as shown in Figure 5.4. There is a clear positive correlation between age and car usage and a negative correlation between age and public transport usage (Train and Bus/tram/metro). Older respondents are thus more attracted to car usage for commuting trips than younger people and vice versa for public transport. Bicycle usage stays quite constant among the age groups.
For higher-educated groups, there is a preference for active modes and public transport. Worth mentioning here is that part of the respondents are from TU Delft and some of them are active in the public transport and active mode sector. This finding brings some bias to the percentages for university-level respondents. Income shows no clear finding concerning differences in mode choice. The only statement extracted from this figure is that lower-income groups have little car usage compared to other income groups. This is partly biased due to the few students in the dataset, but also to lower car ownership among that group.

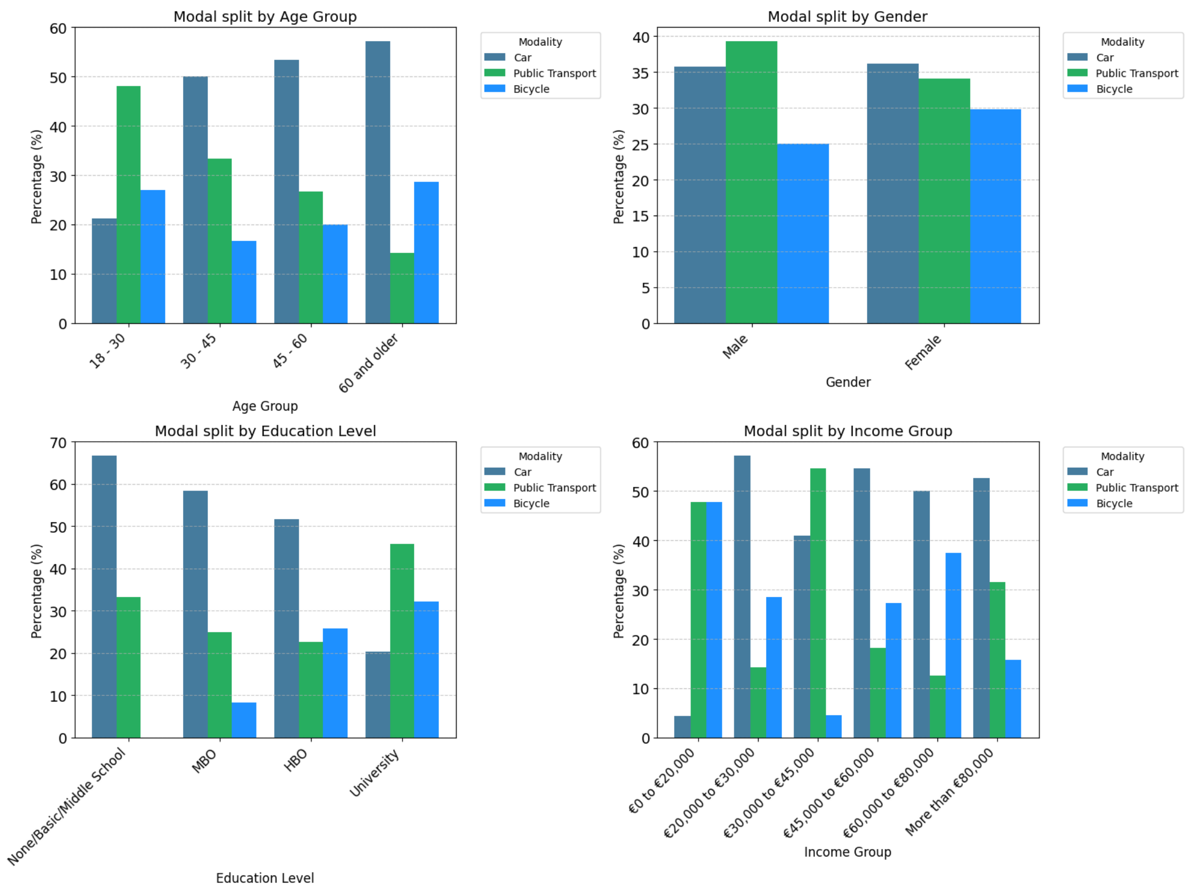


Figure 5.4: Modality variation across the demographic groups

Figure 5.5 reflects on the effect of the perceived parking quality for cars at work. This figure shows that only when parking is not possible or the parking quality is perceived as good, car usage significantly differs from public transport usage. When parking is unavailable, logically no one commutes by car to work, whereas when parking is perceived as good at work, car use is higher (around 60% compared to 40 %).

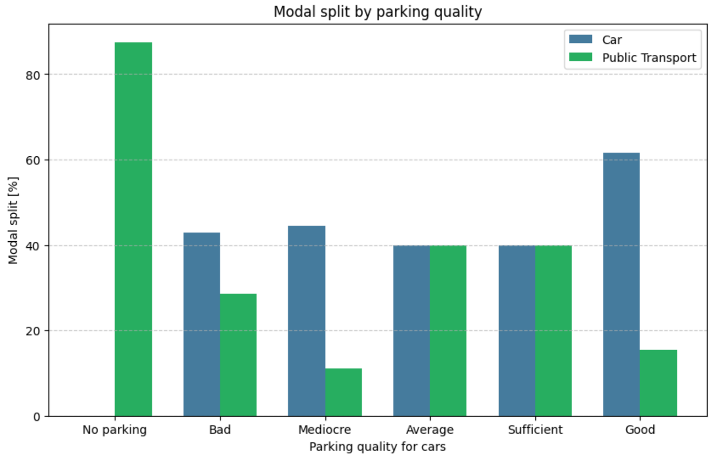


Figure 5.5: Effect of parking quality at work on modal split

5.2.2. Knowledge and attitude

To enhance the modal shift from cars to public transport and shared bicycles, it is important to consider commuters' perceptions of both modes separately. Figure 5.6 describes why current car users opt for the car instead of public transport, despite having the option to go with both modes. Most respondents (67 %) explain that the travel time difference between the car and public transport is the predominant reason not to consider the modal shift to public transport. This implies that two-thirds of the current car users for which public transport is an option indicate that the perception of travel time difference compared to the car demotivates them to consider public transport. In reality, the travel time of public transport could be close to that of the car, but research shows that the perception of travel time in public transport is higher than for the car (Brands et al., 2022) and thus less attractive as commuting mode.

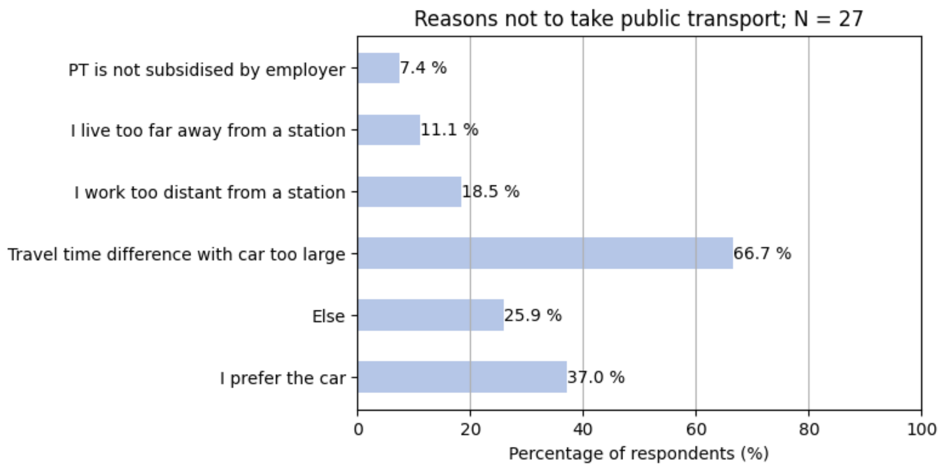


Figure 5.6: Reasons not to take public transport

To investigate the potential of shared bicycles for multi-modal public transport trips as an alternative to the car, the knowledge and attitude of the respondents on shared bicycles are determined. Concerning familiarity, an interesting finding regarding the knowledge of different types of shared bicycle systems is made. As concluded in Figure 5.7, all the respondents, familiar with a shared bicycle (96.2 %), know the concept of OV-Fiets. In contrast, only 27. 6 % of the respondents are familiar with the Donkey Republic bicycle-sharing project and 40 % of the respondents are also familiar with other bicycle-sharing systems than the Donkey Republic and the OV-Fiets. In practice, higher usage rates for OV-Fiets are generally observed than for other systems, hinting to a correlation between familiarity and usage.

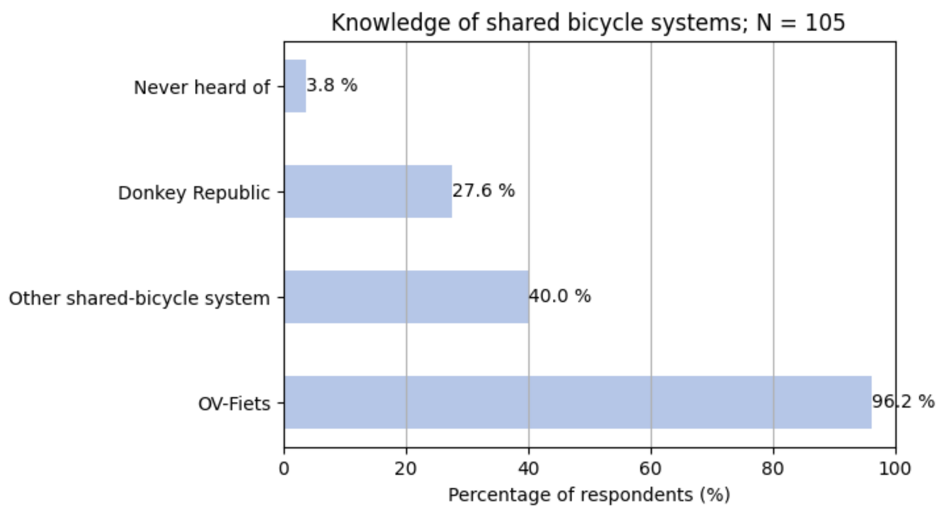


Figure 5.7: Familiarity with shared bicycles

This paragraph discusses the respondents' views on implementing bicycle sharing, focusing on their perspectives regarding suburban commuting. The survey concerned measures related and not related to bicycle sharing, asking respondents to indicate their opinions on these initiatives. Figure 5.8 shows how the respondents see the shared bicycle as a possibility given they are already familiar with them and not currently using them.
The general conclusion is that 54 % of the respondents see no reason to adopt a shared bicycle in their current commuting trip. Furthermore, of the respondents (N = 46) indicating that bicycle sharing can be an option for their trip, 95.7 % (N = 44) comment that this is the case when bicycle sharing is combined with public transport. This conclusion is in line with existing research that shared bicycles and public transport can sometimes be seen as a single integrated system (Kager et al., 2016; Fishman et al., 2015). This research thus emphasises the need for good integration between the two systems to increase adaptation and enhance the modal shift towards public transport and bicycle sharing for commuting.
Figure 5.8 also depicts the low potential for the park-and-ride and shared bicycle combination. This study contradicts the potential by showing a negligible group (5 %) that considers this combination for their multi-modal trip. The possibilities for shared bicycles as an alternative for the private bicycle are also negligible, as only 3 % of the respondents would consider this implementation.

This statistic can also be linked to the current main mode of transport used for commuting trips. Figure 5.9 shows that the current mode choice has a minor effect on the possibilities for bicycle sharing. For car users, bicycle sharing is not an option for just over half of the respondents (60 %). This statistic is slightly lower for current public transport and bicycle users (48.6 % and 53.6 % respectively), but does not vary significantly.

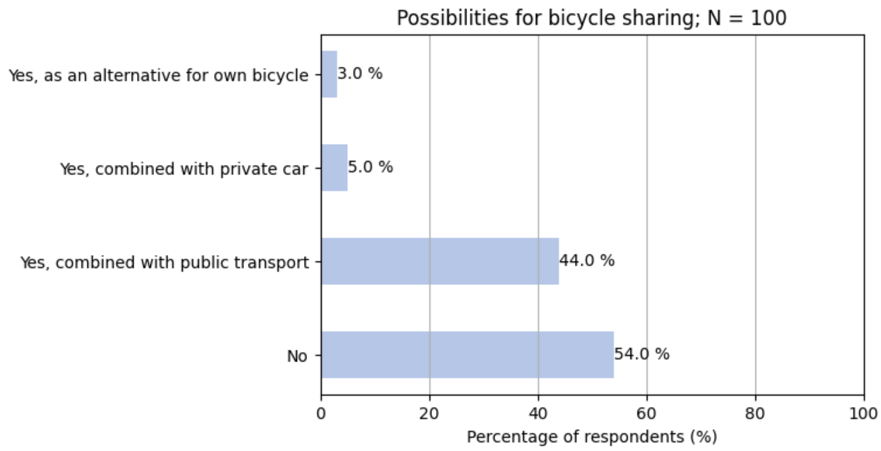


Figure 5.8: General possibilities for incorporating bicycle sharing

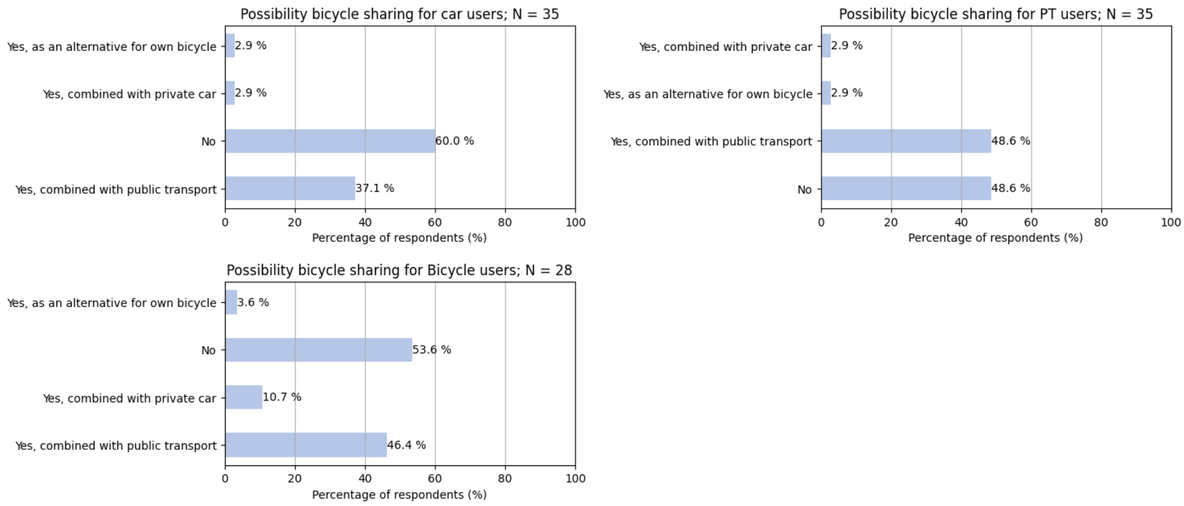


Figure 5.9: Possibility for bicycle sharing for the three main modes of transport of respondents

Most of the respondents have never used a shared bicycle for commuting. Figure 5.11 highlights the reasons for this, with 31.7 % of the respondents comment that work is close enough to the station for their commute. This aligns with research showing that shared bicycle use is optimal for egress distances between 0.5 and 3.5 kilometres (Bachand-Marleau et al., 2012; Fan et al., 2019; Heinen et al., 2010). For commuters who consider their work location to close from a station, the egress distance is computed. This data reveals an average distance of 517 metres with a median value of 350 metres, a maximum value of 1200 and a minimum of 100 metres. This sustains that walking is preferred for egress distances up to 500 metres, but this value can be up to 1200 for some respondents. On the maximum distance, no clear answer can be determined. Eight respondents determined that the egress distance was too large to cycle, but it is mostly unclear which station they meant. For most of this group, the estimated egress distance was between 2 and 4 km, which can be considered an optimal upper bound for the shared bicycle service range.
Donkey Republic collected data on trip distances in the study area Leiden, Katwijk and Oegstgeest. The analysis of this dataset draws a similar conclusion on optimal egress distance for (shared) bicycles. Figure 5.10 shows optimal usage for trips between 1 and 3 km, which sustains the literature and survey.

Another often-mentioned barrier is the availability of shared bicycles. Respondents comment that despite considering shared bicycles, they are not using them due to low availability on their commuting routes. This concludes that investing in more coverage and availability of shared bicycles can slightly improve the usage for the last mile.
Many respondents find having a private bicycle at the station convenient for the last part of their trip. The survey shows that 30.1 % choose this option instead of shared bicycles. This conclusion also aligns with the literature stating that private bicycles are mainly seen as an easy last-mile alternative and replace the need for a shared bicycle among respondents (Krizek, 2011; Teixeira et al., 2023). This finding shows the potential for bicycle sharing to reduce the parking pressure on bicycle parking facilities at (train) stations as highlighted by Jonkeren et al. (Jonkeren et al., 2021). This study also highlights the correlation between the availability issues of shared bicycles and the second bicycle at stations.
A follow-up argument relates to the expenses of shared bicycles. 19.2 % of the respondents consider the shared bicycle too expensive, which matches the conclusion of many studies on shared mobility usage.

Numerous respondents (N = 32) selected the 'Else/Other reasons' section of this part of the survey, which shows some interesting findings. Some respondents comment on the technical barrier of a mandatory account as a barrier. In line with other research in this field (Brand et al., 2017), some respondents commented on the uncertainty of finding a shared bicycle on their route back home as their main reason for not using a shared bicycle. Furthermore, respondents often highlight the lack of inclusion of a shared bicycle in the 'NS-business card' (Public transport card for free public transport) and the fact that the employer does not cover the shared bicycle costs. This statement also relates to the cost aspect of shared bicycles as a reason to choose other modes of transport. A commonly expressed opinion related to shared bicycle use is again that respondents will not consider this modality because the public transport part of the trip does not outperform the car (N = 7). This statement is also highlighted in Figure 5.6 and must be well-considered when implementing shared bicycles for a modal shift away from the car.

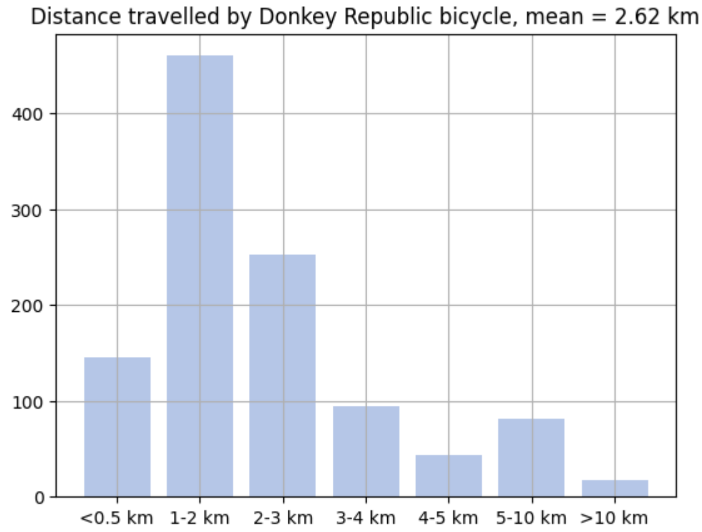


Figure 5.10: Trip length distribution of donkey republic trips in Leiden, Katwijk, Oegstgeest

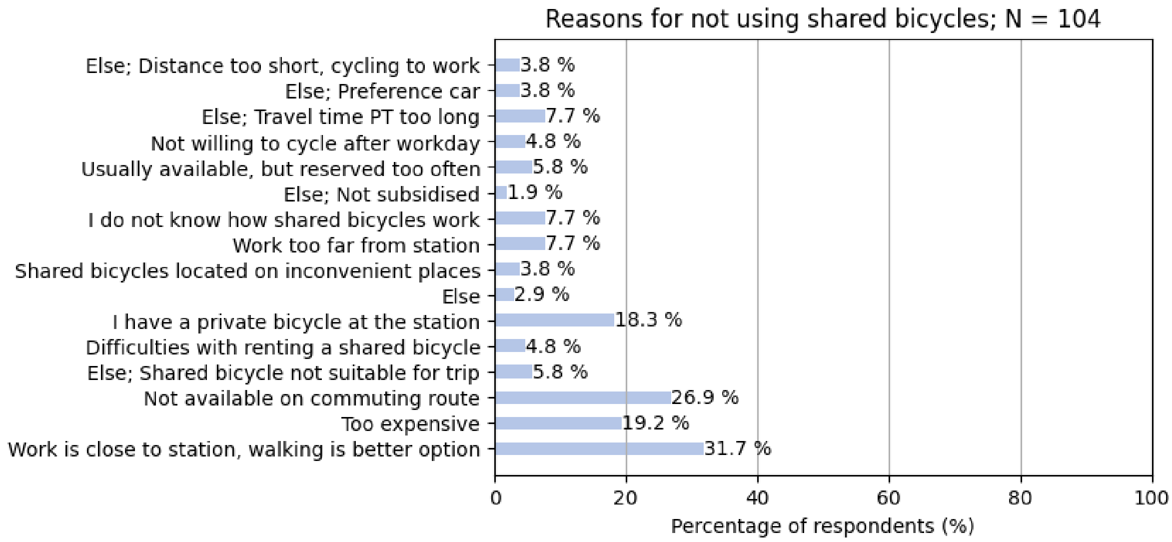


Figure 5.11: Reasons respondents do not use the shared bicycle

A few respondents commented that they experienced difficulties while renting a shared bicycle which creates a barrier for them to keep using bicycle sharing for the last mile. The predominant answers for this statement are related to the time-loss component that discourages renting a shared bicycle and the application usage difficulties. This concludes that investments in making bicycle sharing easily accessible and not time-consuming for users make bicycle sharing a more attractive modality.

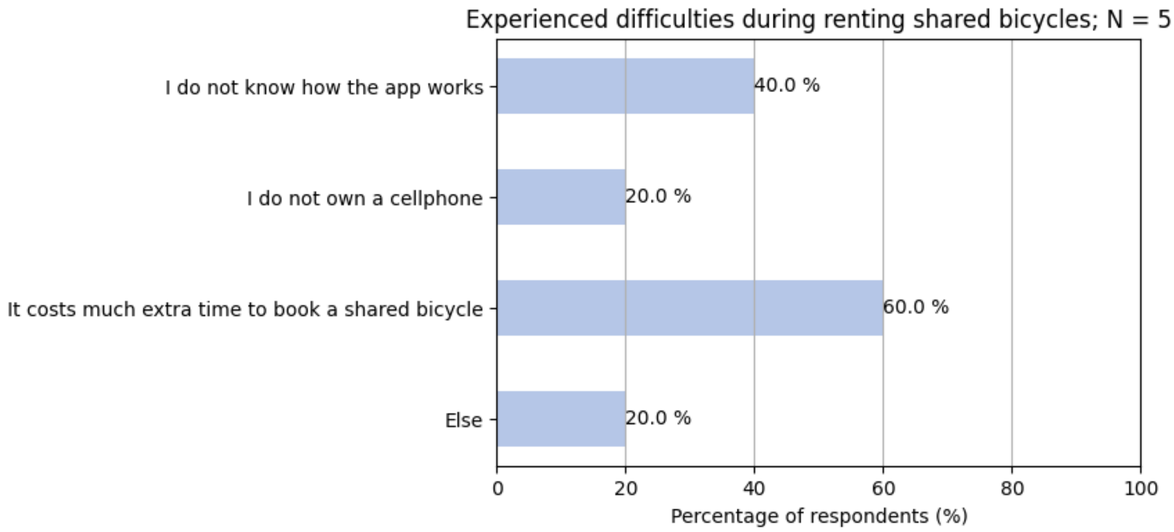


Figure 5.12: Experienced difficulties when renting shared bicycles

Respondents were asked to identify when to consider a shared bicycle for their multi-modal trip, where the results are visualised in Figure 5.13. Two answers are highlighted, which are providing it for free (61.2 %) or subsidies by the employer for the shared bicycles (65.3 %). However, the more interesting conclusion from this diagram is the willingness to use shared bicycles when costs are bundled in a (monthly) membership and the effect of easy bicycle parking and close-by bicycle-sharing hubs. 36.7 % of the respondents that answered this question see potential in bicycle sharing if costs are a periodical instead of a single-use payment. Besides these measures, some respondents (14.3 %) see interventions on the car parking side as a way to encourage shared bicycle usage. Introducing paid parking and cutting on the supply side of car parking could ensure that these respondents consider bicycle sharing and therefore public transport instead of the car. However, this is not the dominant consideration.

The respondents that chose the 'Else' option mainly commented on the availability issue too, while the limitation of the 'OV-fiets' which is Back-to-one (should be returned at the same station) is also addressed. Also here is the issue that the egress side is not the main problem ($tt_{PT} >> tt_{car}$).

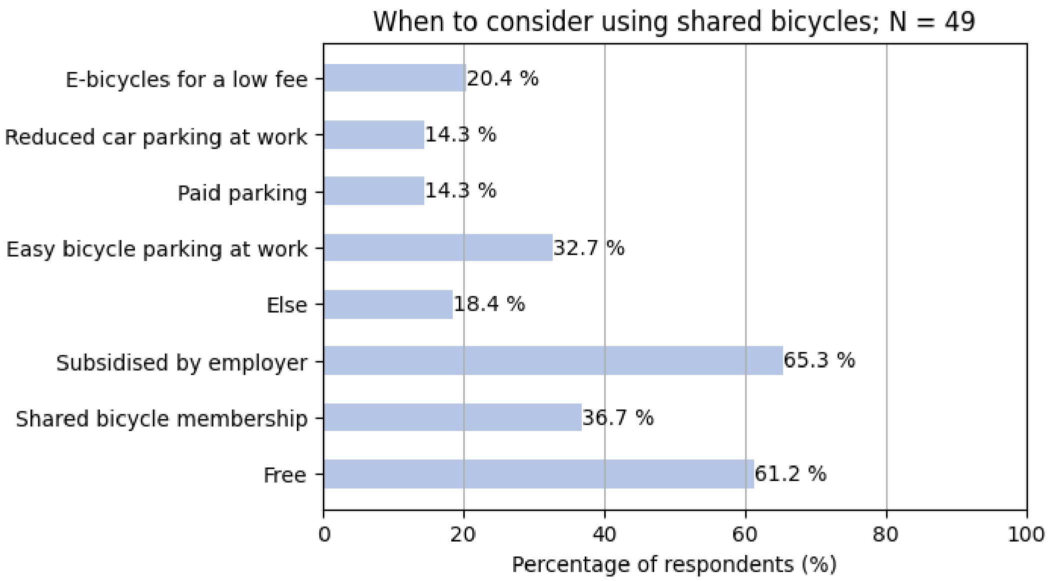


Figure 5.13: When will respondents consider using shared bicycles

To assess why commuters use shared bicycles, it is valuable to regard the respondents who have used a shared bicycle once in the past month. The most common answer is related to the convenience of bicycle sharing. Another part of the respondents comments that alternative transport does not suffice or is not present. Not having a private bicycle at the station resulted in 8 respondents choosing a shared bicycle as the last mile option. For 7 respondents, the alternative last-mile public transport such as a connecting bus from the train station was insufficient, resulting in the bicycle sharing choice. Despite being not the dominant answer (N = 3), parking difficulties at work sometimes resulted in choosing a shared bicycle and public transport instead of the car.

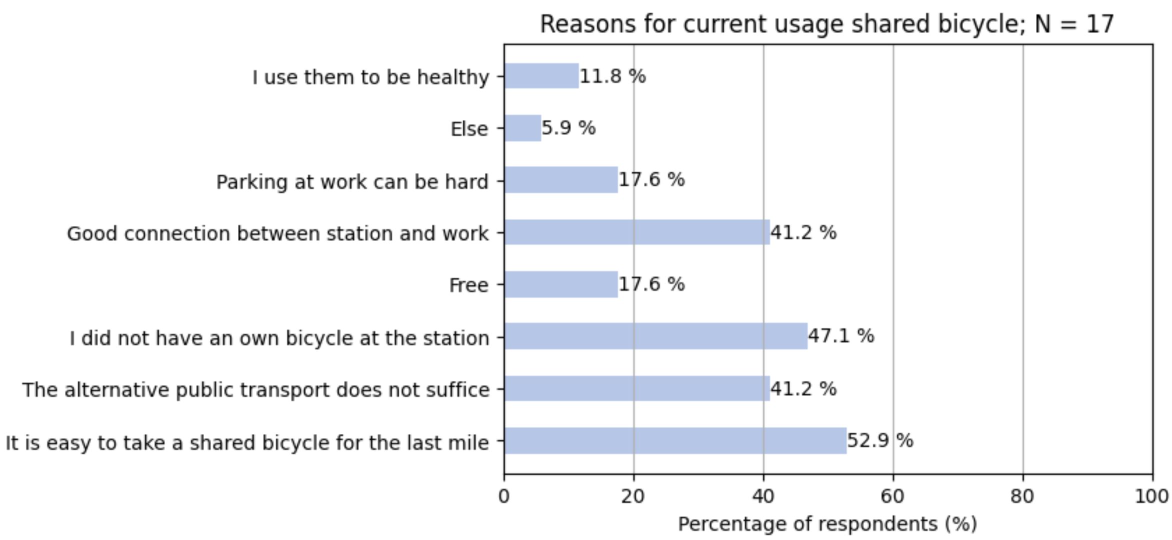


Figure 5.14: Reasons for current usage of the shared bicycle

5.3. Key findings

Regarding the results of the revealed preference and the knowledge and attitude questions, some key takeaways can be extracted, which are summarized below:

- A statement shown in most of the responses is the importance of the role of public transport in the multi-modal trip. Approximately two-thirds of the respondents initially commented that the difference in (perceived) travel time between public transport and the car was the main reason that people did not consider public transport as their mode of commuting. Since the shared bicycle can be mainly used in combination with public transport, as also commented by 95.7 % of respondents who were willing to use a shared bicycle, the essence of well-designed and fast public transport before investing in shared bicycles is highlighted here.
- The main takeaways on why shared bicycle commuters do not use shared bicycles are as follows: The distance being too short or too far between the station and work location, the availability of a private bicycle at the station the functions as a substitution for a potentially shared bicycle, the high costs of shared bicycles, which is not always included in subsidy by the employer or the 'NS business card', and the inconsistent availability or unavailability of shared bicycles at stations is often perceived as a main barrier for not using shared bicycles. Some respondents experience difficulties booking a shared bicycle. These issues mostly relate to the extra time it costs to rent a shared bicycle.
- The potential of the shared bicycle is mostly related to cost-decreasing measures. Respondents mention free and subsidised shared bicycles as large drivers for usage, but also a membership or monthly payment will positively affect the usage of shared bicycles. Also, investing in bicycle parking and shared bicycle hubs at work for shared bicycles is mentioned quite often as a promising intervention to increase shared bicycle usage.
- Shared bikes are the most valued when offering a viable and fast transfer between station and work. Moreover, shared bicycles are mostly used when a private bicycle is unavailable to the respondent. This hints upon the importance of a good transferability and availability of shared bicycles and the possibilities as an alternative for private bicycles.

6

Results of stated preference

This chapter shows the results of the second part of the survey regarding the stated choice experiment. This chapter investigates how trip elements and policy measures affect the mode choice for commuting trips. Chapter 6.1 investigates choice behaviour and analyses the effect of sociodemographic variables. Chapters 6.2 and 6.3 will describe the estimated stated choice model for the base and optimised scenario for sociodemographic effects respectively.
The stated preference analysis addresses sub-question 3: *To what extent will commuters change their travel patterns and mode choices in response to changes in bicycle-sharing infrastructure, public transport and measures discouraging car use?*. Contrary to the revealed preference analysis in Chapter 5, which captures the current system performance, the stated preference analysis complements this by exploring hypothetical scenarios, which are unobservable in current data but critical for forward-looking policy design. This analysis also quantifies sensitivity to factors like costs and travel time.

6.1. Analysis on choice-behaviour and socio-demographics

This section gives a comprehensive overview of the choice behaviour of the respondents, the drivers for their decision-making process and the relation between sociodemographics and choice behaviour. This provides clear initial insights of the choice behaviour and reasoning of the respondents before estimating the discrete choice model (DCM).

Table 6.1: Drivers for choice behaviour stated preference experiment

Factor	Count	Factor	Count
Travel time	41	Environment	2
Costs	27	Cycle distance	2
Comfort and ease	13	Distance	2
Preference Bicycle	5	No e-bicycle necessary	2
Walking time	5	Guarantee car	1
24-h availability	4	Preference active mode	1
Shared bicycle availability	3	Dislike shared bicycle	1
Paid parking	3	Preference PT	1
Uncertainty PT	3		

Table 6.1 explains what factors respondents considered whilst completing the stated preference survey. They were asked to mention their main consideration while opting for an alternative and the number of respondents (count) is shown regarding the type of factor they considered. Most acted based on their cost and time awareness and based their decision-making on the cheapest and fastest alternative. This statement also reflects why respondents will not opt for public transport if the travel time difference compared to the car is disproportionate. A smaller sample comments that comfort and ease

are reasons for their mode choice. This translates to a preference for the car, which is considered a comfortable and easy uni-modal mode.
Moreover, some respondents consider the duration of the shared bicycle rental. 24-hour availability is for some respondents a key factor in preferring shared bicycles over public transport and walking as egress mode. Walking time from hub or station to work is for some respondents a discouraging factor for the corresponding mode and also parking costs are mentioned a few times as a trigger for changing choice behaviour.

Other reasons mentioned by the respondents align more with a general preference for a modality which cannot necessarily be directly captured by a specific β value in the model, such as a cost or time parameter. However, these preferences can be captured with a general constant for the mode *i*: ASC_i. The respondents mentioned general preferences for active modes, public transport, or reasons from an environmentally friendly perspective as starting points for their decision-making. For some, this can mean that public transport and bicycle sharing are preferred over a car.

6.2. Initial choice model

This section introduces the initial model based on the choice behaviour of the respondents. The initial model tries to optimally capture the behaviour according to the model described in Equations 4.1 through 4.4. The initial model disregards any other effect on mode choice and the influence of sociodemographic factors. In short, the model parameters or β thus describe the average effect of the parameters on mode choice.

Table 6.2: Results for the base MNL model

Name	Value		
Number of estimated parameters	11		
Sample size	630		
LL_{init}	-873.37		
LL_{final}	-771.85		
Likelihood ratio test	203.02		
ρ^2	0.116		
$\bar{\rho}^2$	0.104		
AIC	1565.71		
BIC	1614.61		
Parameter	**Value**	**Rob. std err**	**Rob. p-value**
ASC_{PT}	-0.444	0.483	0.358
$ASC_{shared\ bike}$	-0.354	0.234	0.130
$ASC_{shared\ e-bike}$	-0.390	0.192	0.042
β_{costs}	-0.302	0.044	3.75 E-12
$\beta_{parking\ costs}$	-0.168	0.035	2.16 E-6
$\beta_{parking\ time}$	-0.142	0.053	0.008
β_{system}	0.172	0.176	0.330
$\beta_{traveltime\ car}$	-0.088	0.011	2.20 E-14
$\beta_{traveltime\ egress}$	-0.096	0.021	6.25 E-6
$\beta_{traveltime\ PT}$	-0.082	0.017	7.81 E-7
$\beta_{walking}$	-0.097	0.029	8.32 E-4

Where:
ASC_{PT}: The ASC for public transport
$ASC_{shared\ bike}$: The ASC for shared bicycles in addition to the ASC for public transport
$ASC_{shared\ e-bike}$: The ASC for electric shared bicycles in addition to the ASC for public transport
β_{costs}: The parameter for renting costs (in 1/€)
$\beta_{parking\ costs}$: The parameter for parking costs (in 1/€)
$\beta_{parking\ time}$: The parameter for parking time (in 1/min)
β_{system}: The parameter denoting the type of sharing system

$\beta_{traveltime\ car}$: The parameter for travel time for cars (in 1/min)
$\beta_{traveltime\ egress}$: The parameter for egress travel time (in 1/min)
$\beta_{traveltime\ PT}$: The parameter for public transport travel time (in 1/min)
$\beta_{walking}$: The parameter for walking time (in 1/min)
The initial model captures the choice behaviour generically. This model initiates simple alternative specific constants (ASC_i) to capture unobserved utility not captured by the β parameters. At a 95% level of significance ($p = 0.05$), all parameters except the ASC values for public transport, shared bicycles, and the beta for the type of shared bicycle system are significant. This indicates that in the base model, public transport does not differ significantly from the base constant, ASC_{car}. The insignificance of the ASC for shared bicycles exhibits that the constant for public transport + shared bicycle statistically aligns with that for public transport alone. Additionally, the system parameter insignificance indicates respondents' lack of sensitivity to varying shared bicycle systems in the base model.

It is viable that these parameters play a role for certain groups in the dataset. These parameters are still examined with the interaction effects. Furthermore, this model aims to capture the main essence of the model. Therefore, the preference for having the main effects captured instead of removed initially is accounted for during the optimisation of the model.

6.3. Final choice model

This section elaborates on adding sociodemographic variables to increase the model's descriptive accuracy and explains how different demographic characteristics affect preferences for the modalities. The sociodemographic parameters are further assessed in Section 6.3.1. Furthermore, Section 6.3.3 provides an understanding of the final choice model and how various parameters and interaction parameters should be interpreted.

6.3.1. Categorical variables

Socio-demographics

To obtain the sought-after optimal model that describes the behaviour best, the respondents' sociodemographic data is added to optimise the model fit and the descriptive abilities of the model. To find sufficient groups, statistically varying demographic groups with sufficient group size should be identified. An arbitrary value of 10 respondents is used for the minimum group size. A Chi-squared test is performed among the categories to check if groups can be merged based on choice behaviour. This process is more thoroughly explained in Chapter 3. For this study, the number of rows and columns are 2 (2 groups compared) and 4 (4 choice alternatives) respectively. Applying Formula 3.5 gives 3 degrees of freedom, which results in a Chi-squared test statistic of 7.82, given a significance level of 0.05. (Biswal, 2024).

For gender, the Chi-squared test assesses if the groups show different behaviour and thus this attribute can be tested for model improvements. The chi-squared test showed a value of 9.59, thus above 7.82; Hence, the hypothesis of both genders showing similar behaviour is rejected.
The same approach is followed for car ownership, and this test showed a chi-squared statistic of 40.98, resulting in the same conclusion.

The age groups 45-60 and 60+ are merged based on the sample size and chi-squared criteria. The chi-squared statistic for the group 60+ compared to 45-60 equals 5.3, hence smaller than the $p = 0.05$ threshold of 7.82. After merging these groups, the choice behaviour is again compared using Chi-squared, resulting in three new statistically different age groups.
For income groups, €60.000 - €80.000 and €80.000 + show comparable behaviour (χ^2 = 3.89). Due to the behavioural similarity, these two groups are again merged. Also for the adjacent groups €30.000 - €45.000 and €45.000 - €60.000, a low Chi-squared value of 1.56 is found. This finding also results in a new income group from €30.000 to €60.000. For €20.000 - €30.000, despite having a sample size of 7, no evidence is found that this group behaves statistically comparable to the adjacent income groups. This group is therefore treated individually.
The sample size initially judges the education groups. Since just 3 respondents opted for "Alleen basisschool of middelbare school". This group is merged with the MBO group to obtain a new sample

size of 15 respondents. Furthermore, the chi-squared test shows no reason for further merging.

Appendix E shows the full chi-squared analysis of the socio-demographic data, complete with tables showing the mutual chi-squared statistics. Table 6.3 Shows the merged categories based on the chi-squared analysis, which are used to improve the model towards a final model. Also, the new sample size and the reference to the population of South Holland are showcased in this table.

Table 6.3: Merged socio-demographical categories for final model improvements

Demographic	Categories	Sample size	Percentage [%]	Percentage South-Holland [%] [2]
Gender	Male	58	55.2	49.1
	Female	47	44.8	50.9
Age	18-30	52	49.5	19.9
	30-45	13	12.4	24.8
	45+	40	38.1	55.3
Income	0 - €20.000	24	26.1	27.9
	€20.000 - €30.000	7	7.6	21.3
	€30.000 - €60.000	34	37.0	37.1
	meer dan €60.000	27	29.3	13.8
Car ownership	Yes	70	66.7	53.0
	No	35	33.3	47.0
Education	MBO and lower	15	14.3	59.0
	HBO	31	29.5	25.0
	WO	59	56.2	16.0
Travel frequency	0, 1 or 2 times a week	27	25.7	33.2
	3 times a week	27	25.7	15.9
	4 to 5 times a week	51	48.6	50.9

[2] Data sources for demographic data: Age and gender (Centraal Bureau voor de Statistiek, 2024a), income (Centraal Bureau voor de Statistiek, 2024b), drivers licence (Centraal Bureau voor de Statistiek, 2024e), car possession (Provincie Zuid-Holland, 2024a), education (Sociaal en Cultureel Planbureau, 2020) and travel frequency (Kromhout and Souren, 2024; voor de Statistiek, 2024)

Revealed behaviour

Retrieved from the revealed travel behaviour and the finding that habit for a certain mode of transport can influence mode choice behaviour (Lanzini and Khan, 2017), the main mode of transport of the respondents is included in the modelling process. Behavioural differences among the groups are again assessed with a Chi-squared analysis, concluding that the train as a main mode shows similar behaviour as bus, tram or metro travellers. This finding is elaborated on in Table E.4.

Table 6.4: Improved categories for the main mode of transport

Demographic	Categories	Sample size	Percentage [%]	Percentage South-Holland [%] [1]
Main mode of transport	Car	37	35.2	48.3
	Train + Bus/tram/metro (Public transport)	38	36.2	13.2
	Bike	28	26.7	25.8
	By foot	-	-	5.3
	Other modes	-	-	7.3

[1] Main commuting modality retrieved from CBS (2024d). By foot and other modes are appended for completeness.

6.3.2. Model optimisation

Model assessment

To assess the quality of the models, to evaluate if there is a significant difference between the two models and to check if the final model is an improvement compared to the base model and the in-between model optimisation steps, the following set of formulas is applied:

$$\rho^2 = 1 - \frac{LL_{final}}{LL_{init}} \tag{6.1}$$

$$AIC = 2 \cdot LL_{final} + 2 \cdot k \tag{6.2}$$

$$BIC = 2 \cdot LL_{final} + 2 \cdot \ln(N) \cdot k \tag{6.3}$$

$$\lambda_{LR} = 2 \cdot (LL_{final} - LL_{init}) > \chi^2_{1-\alpha,df} \tag{6.4}$$

where: LL_{final} is the likelihood of the full model
LL_{init} is the likelihood of the null model
k is the number of estimated parameters in the model
N is the sample size

First, the model fit will be assessed by the adjusted ρ^2 or $\bar{\rho}^2$ (Equation 6.1 used as a parameter to indicate the model fit by multiple studies (Ton et al., 2020). This parameter assessed the difference in log-likelihood from the initial model where choices are made based on no parameters (throwing a die). The higher the $\bar{\rho}^2$, the better the model fits the choice behaviour.
Secondly, a model can be assessed based on the Akaike information criterion (AIC, Equation 6.2) and the Bayesian information criterion (BIC, Equation 6.3). Both criteria indicate a better fit with a minimal value (Mohammed et al., 2015).
Furthermore, a likelihood ratio test (λ_{LR}, Equation 6.4) assesses statistical differences between the two models. Kosiol et al. (2006). The Chi-squared test is done with again a p-value of 0.05 where the degrees of freedom equal the difference of estimated parameters between the two models that are compared in the analysis (Gavrillidou and Daamen, 2023).

MNL-model with interaction effects

The interaction effects with the individual parameters and the alternative specific constants (ASC) are tested, but when merged, the interaction with the ASC parameters gives insignificant results. Therefore, the model's further optimisation process is performed with interaction effects between the parameters and demographics. However, these interaction effects with ASC parameters can be used to capture unexplained interaction effects later in the optimization process.

160 interaction effects are identified (8 non-ASC parameters in the base model times the number of socio-demographic categories (20)). The interaction effects are tested per parameter per demographic to test which interactions are initially significant, resulting in 77 parameters to include in the model. The results of this analysis are shown in Appendix E. This base model + 77 interaction parameters form the initial model to start the backward elimination process assessing the model fit and significance of individual parameters. For parameter removal, base parameters are excluded since they are initiated to capture the main behaviour whereas the interaction parameters are introduced to capture the behavioural differences among the population, in addition to baseline behaviour.

The removal process of the interaction parameters considered four main factors: Significance levels of the interaction parameters, model improvement, explainability of parameter values and correlations. Due to counter-intuitive phenomena such as cost and time parameters becoming positive when combined with some interaction parameters, interaction parameters with the ASC parameters are reintroduced. Introducing interaction effects with the ASC parameters for the sociodemographic parameters that show counter-intuitive behaviour ensured that the effect is now captured on the ASC parameter and the β parameter interactions show explainable behaviour, whilst improving the model fit given the criteria discussed in Equations 6.1 through 6.4.

6.3.3. Final MNL Model

After backwards elimination and iterating towards a fitting and comprehensive model, Table 6.5 shows the final parameter estimation. This paragraph will evaluate the interpretation and the validity of the model. For the final model, it is important to note that positive interaction parameters do not necessarily imply a positive effect on the mode choice. Interaction parameters should be added to the baseline travel behaviour (that is, $\beta_{costs} = -0.245$ and $\beta_{costs,highfrequency} = 0.149$ mean that the effect of costs for a high frequent traveller is still negative (-0.245 + 0.149 = -0.096)).

Table 6.5: Final MNL model estimation

Name	Value		
Number of estimated parameters	26		
Sample size	630		
LL_{init}	-873.37		
LL_{final}	-670.64		
Likelihood ratio test	405.444		
ρ^2	0.232		
$\bar{\rho}^2$	0.202		
AIC	1393.29		
BIC	1508.88		
Parameter	**Value**	**Rob. std err**	**Rob. p-value**
ASC_{PT}	-0.389	0.561	0.488**
$ASC_{PT,medium\ education}$	-0.794	0.270	0.003
$ASC_{Shared\ bike}$	-0.667	0.260	0.010
$ASC_{Shared\ bike,Mainmode\ fiets}$	0.925	0.249	2.003E-04
$ASC_{Shared\ e-bike}$	-0.476	0.202	0.018
β_{costs}	-0.245	0.058	2.426E-05
$\beta_{costs,18-30}$	-0.284	0.071	6.580E-05
$\beta_{costs,high\ frequency}$	0.149	0.064	0.020
$\beta_{costs,0-20.000}$	-0.242	0.144	0.092*
$\beta_{parking\ costs}$	-0.187	0.039	2.140E-06
$\beta_{parking\ time}$	-0.043	0.062	0.493**
$\beta_{parking\ time,Mainmode\ PT}$	-0.214	0.100	0.033
β_{system}	0.604	0.230	0.009
$\beta_{system,45+}$	-0.518	0.217	0.017
$\beta_{system,high\ frequency}$	-0.600	0.212	0.005
$\beta_{system,20.000-30.000}$	1.160	0.396	0.003
$\beta_{traveltime\ car}$	-0.136	0.016	0.000
$\beta_{traveltime\ car,high\ frequency}$	0.018	0.009	0.054*
$\beta_{traveltime\ car,60.000+}$	0.024	0.009	0.006
$\beta_{traveltime\ car,mainmode\ car}$	0.036	0.009	3.055E-05
$\beta_{traveltime\ egress}$	-0.112	0.023	7.943E-07
$\beta_{traveltime\ PT}$	-0.036	0.020	0.072*
$\beta_{traveltime\ PT,low\ education}$	-0.093	0.019	1.351E-06
$\beta_{traveltime\ PT,female}$	-0.065	0.014	1.983E-06
$\beta_{traveltime\ walk}$	-0.152	0.040	1.421E-04
$\beta_{traveltime\ walk,high\ frequency}$	0.122	0.057	0.031

* Significant on a 10 % significance level

** Insignificant

Including interaction effects with socio-demographics, the model quality significantly improved with an improved $\bar{\rho}^2$ from 0.104 to 0.202. The likelihood ratio test shows a value of:

$$2 \times (-670.64 - -771.85) = 202.42$$

With 15 additional parameters, the 95% chi-squared value is 24.996. This implies that the final model significantly differs from the base model and improves the model fit. Furthermore, a lower AIC and BIC are found for the final model indicating a significant improvement in model quality.

Parameter and interaction interpretation

This model shows that in terms of unobserved utility (captured by the ASC values), all modes are less attractive than the car (ASC_{PT} = -0.389, $ASC_{PT}+ASC Shared\ bike$ = -1.056, $ASC_{PT}+ASC Shared\ e-bike$ = -0.865). However, people currently commuting by bicycle dislike the shared bicycle alternative less in the model. Intuitively, costs reduce utility, with young and low-income groups more sensitive to cost increases, while people with a higher travel frequency are less sensitive. Parking costs are experienced negatively uniformly for the entire population. Although interaction effects with sociodemographics were tested, none showed significant results.

Parking time is slightly worse for current public transport users in addition to the negative baseline. This suggests that current public transport users have a stronger aversion to the car, leading to a negative perception of car parking time. The model shows a general preference for a 24-hour system, which aligns with the findings of Table 6.1. However, People over 45 and high-frequency travellers seem less sensitive to the system type, but still slightly prefer a 24-hour system. Car travel time has intuitively a negative effect on utility, but this effect is less strong for frequent travellers and higher income groups. In addition, current car users show the least negative perception of car travel time, which is explained by a general preference for this mode. No significant difference is found among the travel time parameter for egress modes. Almost no variance between the parameters was found to check whether it could be separated for the different modes. Some runs give huge variations, where ASC parameters explain a large part of the egress travel time. However, this gave no model improvements and a highly insignificant parameter for the egress travel time for shared e-bicycles. The final model shows a negative parameter for egress time for shared bicycles, e-bicycles and buses. Public transport travel time is negatively valued, especially by people with a lower education level and women.

Walking time from hub/station to work is generally valued quite negatively. However, frequent travellers experience this travel time component less negatively and thus account for less disutility. Figure 6.1 displays the ranges that show the values of the minimum and maximum model parameters given the interaction effects to provide a more comprehensive look at the impact of the parameters. The mean values indicated with a dot are determined by simulating the model using the socio-demographic data from South Holland, and the baseline value indicates the parameter value without adding the sociodemographic interaction parameters. The parameter values for the cost and time-related parameters are all in the expected sign, following prior studies on these parameters (Adnan et al., 2019, Montes et al., 2023; Ton et al., 2019; Bachand-Marleau et al., 2012; Fan et al., 2019; Heinen et al., 2010). However, this further quantifies the impact of the parameters on utility. This experiment now shows how the type of shared bicycle system affects the choice behaviour. For most commuters, a 24-hour possession of a shared bicycle is preferred. Table 6.6 compares the model parameters with the initial parameters based on the literature, concluding that the model ranges generally match the literature values.

Parameter	Literature	Model
Travel time car	-0.05 (Weiss et al., 2011; Krauss et al., 2022)	(-0.14; -0.06)
Travel time PT	-0.07 (Krauss et al., 2022)	(-0.19; -0.04)
Egress travel time	-0.14 (Weiss et al., 2011)	-0.11
Parking availability	-0.04 (Krauss et al., 2022)	(-0.26; -0.04)
Parking costs	-0.13 (Weiss et al., 2011)	-0.19
Rental costs	-0.43 (Adnan et al., 2019; Montes et al., 2023)	(-0.77; -0.10)
Walking time	-0.12 (Weiss et al., 2011)	(-0.15; -0.03)
System	x	(-0.53; 1.76)

Table 6.6: Parameter comparison with literature

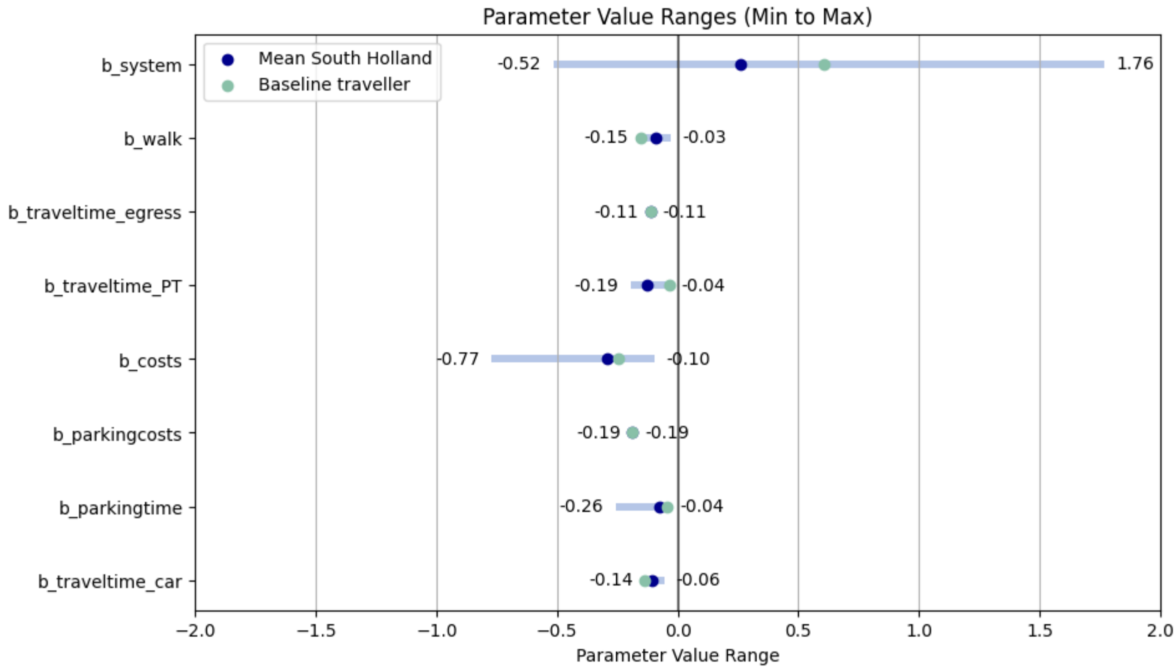


Figure 6.1: Parameter value ranges

In general, public transport travel time ($\beta_{min} = -0.19; \beta_{max} = -0.04$) and car travel time ($\beta_{min} = -0.14; \beta_{max} = -0.06$) contribute similarly to the disutility. On baseline behaviour of the parameters, walking and egress travel time are valued slightly more negatively than car and public transport travel time. The model also shows a clear disutility for cost increments. According to the model, costs are valued more negatively than travel time, which is the case for car parking and shared bicycle costs. The baseline parameters for walking and egress time show lower values than those for public transport travel time. This implies that each extra minute of egress time or walking time is perceived as worse than one minute of in-vehicle travel time.

Value of time

An indicator to clarify how costs and travel time coincide for this model, it can be valuable to determine the value of time (VoT). Since the cost parameter refers to shared bicycle costs, the VoT can be calculated for the travel time of the egress leg and walking time and is calculated by applying equation 6.5.

$$VoT = \frac{\beta_{tt}}{\beta_{costs}} \tag{6.5}$$

Given the parameter ranges for egress travel time and the costs presented in 6.1. The VoT parameter for egress travel time ranges from €66.00/h to €8.40/h with a simulation average of €0.37/min. These values indicate the amount of money people are willing to pay extra per minute for additional egress travel time. For walking, these values range from €90.00/h to €2.40/h with a simulation average of €18.00/h. In the literature, a comparable, slightly lower value of € 16.20/h is found for cycling that addresses the VoT parameter for cycling (Börjesson and Eliasson, 2012). To clarify the implication of bicycle sharing optimisation measures on travel time acceptance, an example is given concerning free bicycle sharing. A free OV-Fiets (€2.28 per trip/€4.55 per day to €0) ensures that commuters accept an additional cycle time of 6.1 minutes.
It should be mentioned that VoT values as €66.00/h and €90.00/h are unlikely in practice and only describe the highest possible VoT value given the parameter ranges for the cost and time parameters. Despite being a feasible, though unlikely, value, the simulation average provides a more comprehensive and realistic representation of the value of time.

6.4. Key findings

Respondents reveal that cost- and time-related parameters primarily influence their choice behaviour. In addition, they see comfort and ease as secondary but important, often associated with the benefits of unimodal car trips. In addition, walking time and 24-hour availability are mentioned a few times, indicating that this does affect choice behaviour and should be kept in the model.

The initial choice model shows negative values for all the parameters related to time and cost, which aligns with the literature and the influential factors on choice behaviour, as indicated by the respondents. Moreover, the 24-hour system is preferred, as indicated by a positive parameter value. The initial model also shows a preference for car commuting compared to other modalities, where bicycle sharing is even less preferred compared to only public transport. Including interaction parameters between separate parameters and sociodemographic data improves the model (The log-likelihood value decreases from -771.85 to -670.64 and the rho-square-bar value increases from 0.104 to 0.202). The final model contains 11 baseline parameters and 15 additional interaction effects and reveals similar baseline behaviour compared to the initial model.
The final model adds that shared bicycle usage is less negatively experienced among current bicycle users. Related to average behaviour, an extra euro for renting costs is valued three times more negatively than an additional minute of travel time by car, train, and egress mode. Costs are valued most negatively by younger and low-income groups. It shows that lower-educated and female travellers dislike travelling by public transport more compared to other travellers. Furthermore, high-frequent travellers have a less strong preference for 24-hour systems, are more keen on walking between station and work locations, are less sensitive to cost increases and are slightly less affected by car travel time than the baseline traveller. Lastly, The final model shows that parking time for the car is valued worse per minute for commuters that mainly use public transport and that lower/middle income commuters strongly prefer a 24-hour bicycle-sharing system

7

Model implementations and system recommendations

This chapter employs the model discussed in Chapter 6 to give a comprehensive view of hypothetical modes of transportation, given the adjustments of the system in shared bicycles, public transport, and the car complemented with relationships to the areas of the case study and revealed preferences data. The general simulation is shown in Chapter 7.1 and Chapter 7.2 describes the persona-based model analysis. This analysis uses the behaviour quantification from the stated preference experiment to further elaborate on the following sub-question:

Sub-question 3 - To what extent will commuters change their travel patterns and mode choices in response to changes in bicycle-sharing infrastructure, public transport and measures discouraging car use?

7.1. Simulation and model application

The equation for the MNL model (Ambo et al., 2021) applied in this study can be rewritten to the formula highlighted in Equation 7.1 below. This model translates the attribute levels into utility and sequentially into probabilities.

$$P_j = \frac{\exp(U_j)}{\sum_{j=1}^{J} \exp(U_j)}, \quad j = 1, 2, \ldots, J \tag{7.1}$$

7.1.1. Example case Drechtsteden and Leiden

This paragraph analyses a commute from Barendrecht near the station to IV-Infra b.v., a company in Sliedrecht, and from a neighbourhood within walking distance of the Alphen aan de Rijn station to Janssen Biomedics in the Leiden BioScience park. Both companies are within the range of 1 to 3 kilometres from a (suburban) train station and for Janssen Biomedics, research from the province targets this location. Hence, the choice for both work locations. Both trips are highlighted in Chapter 3.1.5.

The travel times are based on Google Maps data (Tuesday, 9:00, fastest route for both modes). The costs of the shared bicycle are based on the current prices for the OV-fiets and OV-e-bike (Nederlandse Spoorwegen, 2024a), whereon the type of bicycle sharing system is also based. The OV-fiets has a daily rate of €4.55, and €13 for an electric bicycle, so for the station-work trip, the price is divided by two. Parking time is arbitrarily set to 2 minutes. Tables 7.1 and 7.2 summarise the attribute levels that function as input values for the simulation. Table 7.3 introduces the scenarios assessed in this section and the corresponding attribute values for the simulation.

Table 7.1: Attribute levels for the case study trip Drechtsteden

	Car	PT + Shared bicycle	PT + Shared E-bicycle	PT only
Travel time	25 minutes	35 minutes	35 minutes	35 minutes
Egress time	-	6 minutes	4 minutes	0 minutes
Walking time	-	1 minutes	1 minutes	19 minutes
Total travel time	25 minutes	42 minutes	40 minutes	54 minutes
Shared bicycle costs	-	€ 2.28	€ 6.50	-
Parking costs	€ 0	-	-	-
Parking time	2 minutes	-	-	-
System	-	24-hour	24-hour	-

Table 7.2: Attribute levels for the case study trip Leiden

	Car	PT + Shared bicycle	PT + Shared E-bicycle	PT only
Travel time	25 minutes	20 minutes	20 minutes	20 minutes
Egress time	-	10 minutes	6 minutes	7 minutes
Walking time	-	1 minutes	1 minutes	7 minutes
Total travel time	25 minutes	31 minutes	27 minutes	34 minutes
Shared bicycle costs	-	€ 2.28	€ 6.50	-
Parking costs	€ 0	-	-	-
Parking time	2 minutes	-	-	-
System	-	24-hour	24-hour	-

Table 7.3: Summary of the alternatives

Alternative	$^{1}costs_{SB,SEB}$	$^{1}tt_{SB,SEB}$	$system$	tt_{walk}	$t_{parking}$	$costs_{parking}$
1 - Free Shared bicycle	€0; €6.50	-	-	-	-	-
2a - Donkey Republic	€1; €2.80	4; 3	single ride	8; 8	-	-
2b - Donkey Republic Leiden	€1; €2.80	-	single ride	2; 2	-	-
3 - Donkey Republic improved hub	€1; €2.80	-	single ride	-	-	-
4 - Paid parking	-	-	-	-	4	€2
5 - E-bicycle same price	€2.28; €2.28	-	-	-	-	-
6 - Combination free shared bicycle and paid parking	€0; €6.50	-	-	-	4	€2

[1] SB and SEB imply shared bicycle and shared e-bicycle

Applying the attribute levels in a simulation with a sample size of $N = 40000$, the model shows the following base-case models for Drechtsteden and Leiden respectively: For the Drechtsteden case, 84.3 % of the people are expected to go by car. This significant share is explained by the difference in travel time between cars and public transport. Therefore sustaining the finding from Chapter 5 that the performance difference between the two modalities is for most respondents a reason not to consider public transport, let alone shared bicycles. The other 15.7 % are expected to take public transport as their main mode, where 6.9 % use a shared bicycle as the last mile, 2.5 % a shared e-bicycle, and 6.3 % use walking as egress mode.

For Leiden, 68.9 % commute by car, which is significantly lower than for Drechtsteden. This statement can be sustained by the more competitive travel times between car and transit. A slightly larger share of public transport trips (14.6 %) uses a bus and walking as egress, expected to be caused by the larger egress distance (2.3 km). Compared to Drechsteden, a larger share of shared bicycle users opt for the regular shared bicycle over the electric alternative (10.6 % to 5.9 %) due to the costs not outweighing the travel time reduction.

Alternative 1: Free/subsidised shared bicycle

The first scenario demonstrates the inclusion of the shared bicycle in the free public transport card provided by the employer. There is a lot of potential for shared bicycles but their costs remain a reason for people to reconsider their modalities. Subsidising shared bicycles and monthly memberships can offer solutions as concluded from Chapter 5, literature and the vision of Provincie Zuid-Holland (Deelfiets, 2024).

For both Drechtsteden and Leiden, a free shared bicycle decreases the share of cars by 3 to 4 %pt. and increases the share of people opting for the shared bicycle as the last mile modality by 4.3 and 6.9 %pt. This system adjustment mostly forces a direct modal shift from cars to public transport and shared bicycles, whilst having a minor effect on shared e-bicycles and public transport + walking.

Alternative 2: Donkey republic

The Drechtsteden and Leiden have placed Donkey Republic bicycles on quite some stations including the ones for both the case studies. Given the location of the hub and drop-off points for Donkey bicycles, the travel time becomes 4 minutes on a normal bike and 3 on an e-bicycle, with a walking time from the hub to work of 8 minutes for Drechtsteden and 10 and 6 minutes for Leiden with a walking time increment to 2 minutes. The price of those bicycles is €1 for regular bicycles and €2.80 for an e-bicycle per trip according to the Donkey Republic app.

The model shows similar values for the modal split in Leiden compared to the base scenario and a higher car share in Drechtsteden. This implies that for Leiden, the Donkey Republic system can compete with the OV-Fiets given the current system, but for the Drechtsteden, the OV-Fiets outperforms the Donkey Republic system. This behaviour can be explained by the travel time increment of 6 minutes while the cost reduction is just €1.28 for the regular shared bicycle. Given the average VoT of €0.30/km for walking, 4 minutes extra walking time for egress is maximally justifiable, explaining the decrease in share for the shared bicycle.

Alternative 3: Donkey republic with a hub at work

Donkey Republic lacks in the fact that it is a hybrid bicycle-sharing system with designated drop-off points. These drop-off points can be designed and placed by policymakers and Donkey Republic itself. This adjustment will assess the effect of a Donkey Republic hub at the work location to judge the benefit of a Donkey Republic system with an optimal hub location, since literature shows bicycle parking proximity to enhance the usage (Fishman et al., 2015).

This adjustment is more effective than the base Donkey Republic scenario but has a minor effect on car usage. The key comment regarding this minor effect is that the Donkey bicycle is not available for the entire day but is considered single-ride. The model thus shows a less effective decrease in car

Alternative 4: Parking costs to €2 and parking time + 2 min

One of the possible adjustments retrieved from the literature study and the qualitative survey was parking adjustments for cars to discourage car trips (Buehler, 2012; Currie and Delbosc, 2011). This scenario assesses the effect of parking costs and an additional effort to park the car at the office.

Paid parking decreases the car share by 5.3 and 9.4 %pt respectively for Drechtsteden and Leiden. However, this intervention primarily impacts the share of public transport without bicycle-sharing options, making it less effective than cost-reduction measures for bicycle sharing. Nevertheless, it proves highly effective in terms of overall reduction. In general, car parking interventions assist with a deduction of car users. However, these are not the best interventions to attract shared bicycle users.

Alternative 5: E-bicycle same price as regular bicycle

To investigate to what extent the modal share of shared e-bicycles increases and how this intervention affects the share of car trips, a scenario is assessed where e-bicycles are as expensive as regular bicycles. This scenario is initiated to assess the potential of shared e-bicycles and to identify if the costs are a main barrier to that potential (Jorritsma et al., 2021; Campbell et al., 2016)

The model shows that the intervention decreases the share of car trips by 2.5 and 4.1 %pt for Drechtsteden and Leiden respectively, but mostly becomes an alternative for public transport options with and without bicycle sharing. A second implication of this result is that when priced equally, there is no preference for a shared e-bicycle over a shared bicycle in the Drechtsteden case. In Leiden, however, a slightly higher share of electric bicycles than regular bicycles is visible, which can be explained by the larger egress distance where the electric bicycle outperforms the regular bicycle on travel time.

Alternative 6: Combination free shared bicycle and parking interventions

This intervention regards the two most car-reducing scenarios to test the combined effect.
This intervention immediately shows a significant additional share for the shared bicycle of 7.5 and 11.5 %pt where the car is chosen 9.4 and 14.1 %pt less respectively for both cases. This solution tackles the best of both interventions, where car usage is reduced significantly and shared bicycle usage is enhanced.

All the results of the simulations are further summarised in Table 7.4 and Table 7.5. In both tables, the absolute modelled effect of the 6 system adjustments is given in percentage modal share (%) together with percentage point (%pt) difference compared to the base scenario. Both tables are visualised using clear barplots in Figures 7.1 and 7.2. Noteworthy is that the simulation results denote the potential of shared bicycles, implying the shared (e)-bicycle is available for every extra commuter.

Table 7.4: Effect of system adjustments on modal split Drechtsteden

System adjustment	Car	PT + Shared bicycle	PT + Shared E-bicycle	PT only
Base scenario	84.3	6.9	2.5	6.3
Free shared bicycle	80.7 -3.6	11.2 +4.3	2.4 -0.1	5.7 -0.6
Donkey Republic	85.8 +1.5	5.1 -1.8	2.8 +0.3	6.3 +0.0
Donkey Republic improved hub location	83.6 -0.7	6.4 -0.5	4.0 +1.5	6.0 -0.3
Paid car parking	79.0 -5.3	9.1 +2.2	3.4 +0.9	8.5 +2.2
E-bicycle same price	81.8 -2.5	6.0 -0.9	6.4 +3.9	5.9 -0.4
Combination free shared bicycle and paid parking	74.9 -9.4	14.4 +7.5	2.9 +0.4	7.8 +1.5

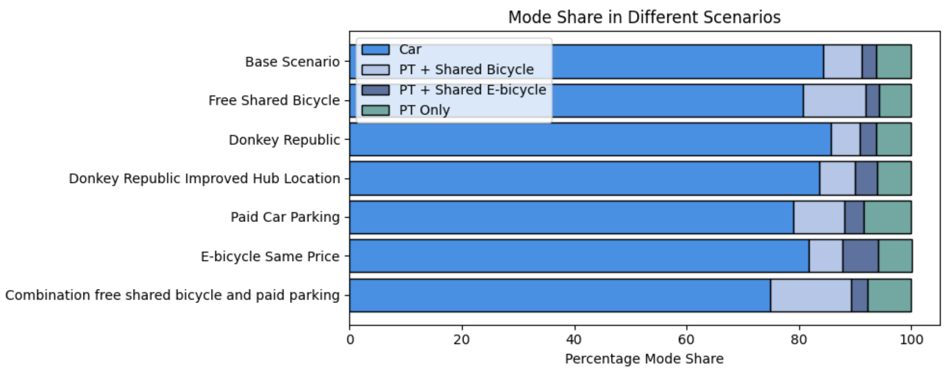


Figure 7.1: Barplots system adjustments Drechsteden

Table 7.5: Effect of system adjustments on modal split Leiden

System adjustment	Car	PT + Shared bicycle	PT + Shared E-bicycle	PT only
Base scenario	68.9	10.6	5.9	14.6
Free shared bicycle	64.6 -4.3	17.5 +6.9	4.4 -1.5	13.6 -1.0
Donkey Republic	68.7 -0.2	9.5 -1.1	7.3 +1.4	14.5 -0.1
Donkey Republic improved hub location	67.8 -1.1	9.9 -0.7	7.9 +2.0	14.3 -0.3
Paid car parking	59.5 -9.4	13.9 +3.3	6.6 +0.7	20.1 +5.5
E-bicycle same price	64.8 -4.1	9.4 -1.2	11.9 +6.0	13.9 -0.7
Combination free shared bicycle and paid parking	54.8 -14.1	22.1 +11.5	5.6 -0.3	17.5 +2.9

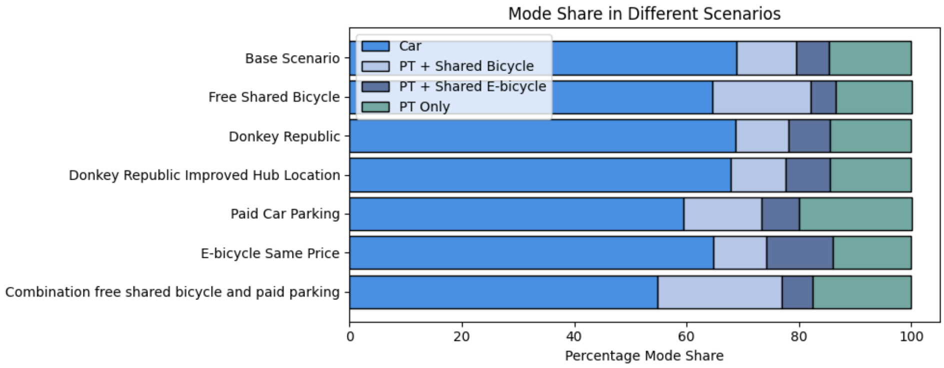


Figure 7.2: Barplots system adjustments Leiden

Effect of Car to public transport travel time ratio

A dominant conclusion throughout this research is the marginal effect of public transport travel time. Often commented on within the qualitative part of the survey is the non-competitiveness of public transport travel time with car travel time which diminishes parts of the potential for bicycle sharing. This paragraph highlights the effect of this ratio on the modal share according to the model. For the Drechtsteden case study, the main public transport leg travel time ratio compared to the car is shown in Figure 7.3.

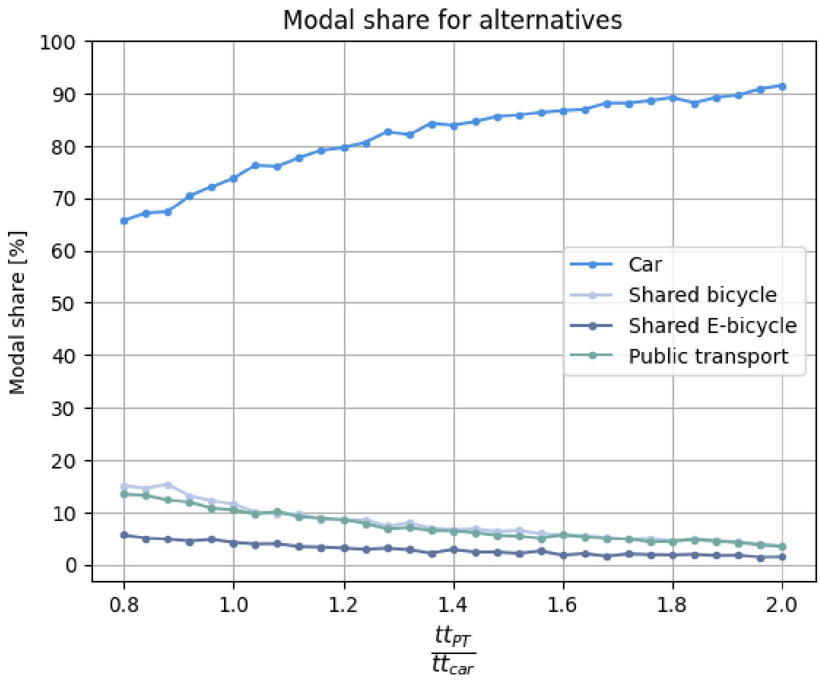


Figure 7.3: Modal share for different travel time ratios ($N_{sim} = 40.000$)

It shows directly that at a ratio of 1:2 for tt_{car}:tt_{PT}. Only around 8 % consider public transport in the base scenario in which shared (e)-bicycles are considered less than 5 % of the time. This also affects the potential of bicycle-sharing interventions and highlights again the importance of the competitiveness between cars and public transport. Figure 7.4 supports the statement that the adjustment effect on the car modal split diminishes the higher the tt_{car}:tt_{PT} ratio is.

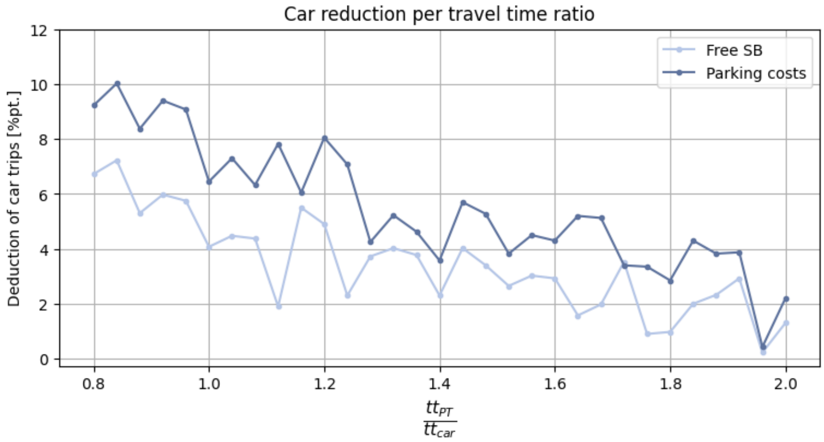


Figure 7.4: Effect of free shared bicycle and car parking costs adjustments on car share for different ratios ($N_{sim} = 40.000$)

Potential of e-bicycles

The model also highlights a critical assessment of the need for shared E-bicycles. With the original price scheme (Nederlandse Spoorwegen, 2024a) and the Drechtsteden case study considered. E-bicycles become more dominant from 7.25 kilometres egress distance onwards, given the car is no alternative. However, if the car is still taken into account, 98 % will take the car as a commuting mode. Hence, the potential for shared bicycles is almost negligible. The main potential for shared bicycle enhancement is found at lower distances, where the additional time win for shared e-bicycles does not outperform the extra costs. So in suburban areas, despite the potential for e-bicycles at higher egress ranges, the car becomes profoundly dominant which diminishes the potential for bicycle sharing intervention and thus for the shared (e)-bicycle.

7.1.2. Application conclusions

The practical application of the model foregrounds and quantifies the varying impacts of the system adjustments on commuting behaviour. Cost-related interventions show the most significant impact on car usage. Free shared bicycles create a notable modal shift from cars to combined public transport and shared bicycle usage, while car parking costs enhance a similar shift towards public transport alone. The Donkey Republic system enhances a modal shift but depends on an optimal hub location, minimising egress travel time. This scenario, combined with cost-beneficial alternatives can further enhance shared bicycle usage. Noteworthy, the Donkey Republic only introduces a small decrease in car usage (0.7 to 1.1 %pt with optimal hub location), mainly benefitting the shared e-bicycle due to its significant cost drop. Introducing similar costs for the OV E-bike and the regular OV-Fiets shows a considerable modal shift. However, a smaller cost decrease for a regular shared bicycle imposes a larger effect on car usage.

The simulation reveals limited potential for shared E-bicycles in suburban areas. 98% of commuters opt for car commuting at longer egress distances despite the potential of e-bicycles. The main opportunity for enhancing shared bicycle use lies at shorter distances, where time savings from E-bicycles do not outweigh the additional costs, making regular shared bicycles more desirable.
Finally, the model application shows that the potential after different interventions depends on the difference in travel time between car and public transport. An adjustment in the Drechtsteden case where the travel time ratio between car and public transport is varied between 1:0.8 (10 min in car to 8 in PT) to 1:2 (10 min in car to 20 in PT) concludes that the effect of dominant interventions (free shared bicycles and parking costs) decreases car use with just 1 to 2 %pt if the ratio is close to 1:2. Furthermore, it is crucial to know that the results depend on availability of shared bicycles. This part of the research assumes that all modes are available to the respondent, implying that the results showcase the optimal benefit of the adjustments. This should be constantly considered when interpreting the effect of the system adjustments. However, the simulation results still provide valuable insights into the magnitude of the adjustment's effects.

7.2. Personas

This section introduces different personae to conceptualise attribute adjustments' effect on target groups. This section recalls the case study areas where Provincie Zuid-Holland invests in shared bicycle programs. This analysis distinguishes the need for different system adjustments based on more specific target groups so that concrete adjustments can be proposed per demographic group. Again, note that the experiment assumed all modalities to be present to the respondent. Given this assumption, the demographic "no car possession" does not imply a modal share of 0 % for the car. The outcome of the persona-based study can therefore be interpreted as their willingness to use a certain mode expressed in a probability. Figure 7.5 introduces the personae used for this analysis.

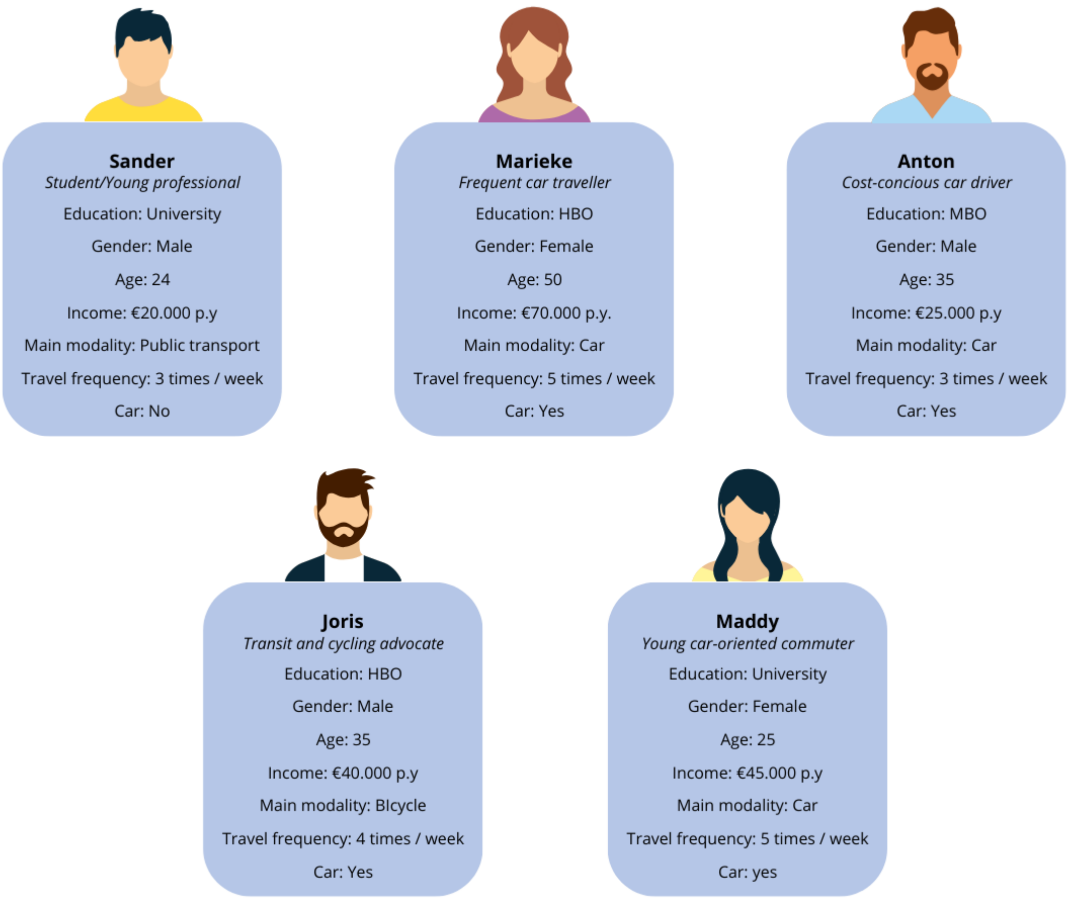


Figure 7.5: Demographic data of the personas

The specific persona characteristics are derived from the interaction parameters from the final model, as shown in 6.5. A variance in commuters with a high and medium/low frequency is included in the persona simulation. This parameter affects cost-sensitivity, willingness to walk in egress mode, car travel time and the preference for a 24-hour sharing system. So **Sander, Anton and Joris** are non-frequent commuters and **Marieke and Maddy** are frequent travellers. Diverse education, gender, income and age levels are varied across the personas to tackle various combinations of these characteristics. These characteristics are included in most of the significant interaction parameters. Hence, to show diverse preferences for modalities, it is necessary to create various combinations with these characteristics including the travel frequency (For example: A low-educated, low to medium income level male (**Anton**) versus a high-educated, high-income female with a high travel frequency (**Maddy**)).

7.2.1. Base and adjusted trip outcome

Figure 7.6 visualises the modal probability for each persona in the base scenario, given the specific characteristics of the different personae.

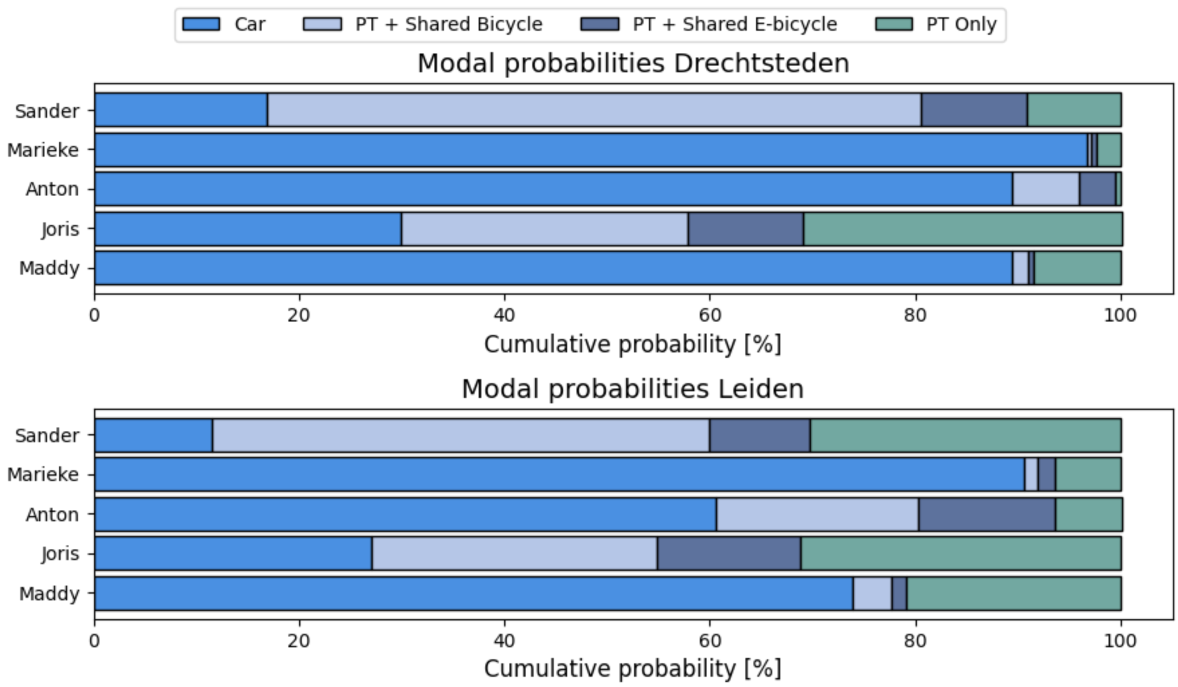


Figure 7.6: Cumulative mode probability for the different personae for the base scenario

The Drechtsteden and Leiden cases generally show similar results for the modal probabilities. Noteworthy is that **Sander** and **Joris** value public transport and bicycle sharing quite high, sustained by their higher education and gender. Higher and medium-educated men are less sensitive to increasing public transport travel time. Their modal probability for the car does not increase significantly with increasing public transport travel time. These findings expand to the conclusion that **Marieke** and **Anton** relatively increase their probability to use public transport more than other personae in the Leiden case compared to the Drechsteden case, where public transport travel time competes more with the car.

An adjustment decreasing car usage the most for all personas is introducing car parking costs. Despite the initial probabilities among the modes, this adjustment results in the highest car reduction, especially when combined with the free bicycle-sharing incentive. Another highlighted finding is the difference in the modal shift in response to the Donkey Republic system. For **Sander** and **Anton**, switching the OV-Fiets concept to Donkey Republic increases the probability of taking the car by 5 to almost 20 %pt respectively. This phenomenon is subject to their young age and low to middle income. These demographics have a strong preference for the 24-hour system, For electric Donkey bicycles, this effect is less strong, mainly due to the greater cost reduction, which makes them more competitive with regular shared bicycles with this adjustment.
The persona-based analysis also highlights the general preference of middle-income and non-frequent commuters to switch to bicycle sharing instead of the regular public transport option. The lower weekly commuting frequency disbenefits their walking time perception and affects the cost sensitivity less. The results for **Anton** emphasise that lower education strongly affects the probability of taking public transport and bicycle sharing. The demographics of **Anton** hint towards bicycle sharing. However, the probability of car use decreases maximally when combining paid parking and free bicycle sharing, showing a value of 10.9 %pt to 78.5 %.
Given this finding and the model output, an additional modification for **Anton** with demographics: lower-income and woman, is initiated, showing a potential shift of only 0.5 %pt to 99.2 % probability for the car. Figure 7.7 visualises the probability of car usage for the five personae across the adjustments, which concisely highlights and sustains the findings of this paragraph.

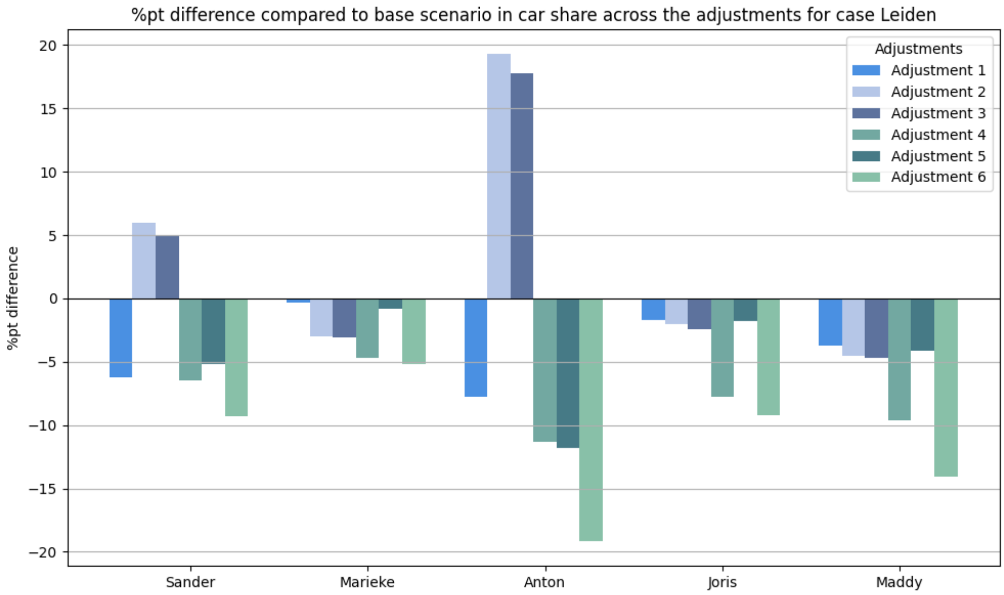


Figure 7.7: Modal probability changes for the car given the personae and 6 alternatives for Leiden

7.2.2. General conclusion persona-based simulation and link to case study

The persona-based study explicitly highlights differences across the demographic groups. A young male starter with a university background generally shows more affinity for bicycle sharing and public transport. However, for a person fitting these characteristics, the concept of Donkey Republic is counterproductive for car reduction. Hence, the OV-Fiets is the more suitable option. Their affinity with public transport is described by the smaller influence of public transport travel time compared to women on choice behaviour and despite their larger aversion to costs, the low to medium starter income, which strongly prefers 24-hour sharing systems, shows lower preference for the donkey republic system (single ride) compared to the base case (OV-Fiets - 24-hour system). Frequent car travellers are intuitively more eager for car usage than sustainable alternatives. To enhance the usage of public transport and shared bicycles for this particular target group, car-discouraging alternatives (parking costs and reduced parking capacity) show the most significant effect. The infrequent car driver generally prefers the car, depending strongly on the travel time difference between the car and public transport. They strongly prefer cheaper alternatives, so cutting shared bicycle costs and increasing parking costs are effective measures for this group.

These findings relate to, for example, the higher-educated Bio-Science park in Leiden. The Bio-Science park is most likely a mix of **Sander**, **Maddy** and **Marieke**, where higher education and higher income are well represented. A mix of cheaper shared bicycles and car-discouraging incentives with a combination of Donkey Republic bicycles with improved hub locations (**Maddy** and **Marieke**) and the OV-Fiets which can be possessed for 24 hours (**Sander**) show optimal potential for the shared bicycle usage. Moreover, the results can also be coupled with more industrial areas around the Drechtsteden. This study expects **Anton** to fit the commuters to this area best. Lower-educated and car-oriented commuters align best with the industrial workforce in the Drechtsteden. Furthermore, it should be mentioned that the areas are mostly poorly accessible by public transport and often further away from train or larger bus stations. The persona-specific preference for car commuting and poor accessibility by public transport foreground minimal potential for bicycle sharing for these areas and target groups. Note that in this research, the personae represent specific demographic combinations and extreme scenarios based on the model parameters found in Chapter 6.

8 Conclusion

This research highlighted some interesting findings on the implementation of shared bicycles, the various factors that improve the (combined) usage of shared bicycles and public transport, the marginal effect of adjusting the shared bicycle system, and general adjustments regarding suburban commutes. This chapter addresses the key findings on these topics, structured around the main question of this study: *How can adjustments in the shared bike system enhance the use of public transport as the primary commuting mode, offering a viable alternative to cars in suburban areas of South Holland?*

SQ.1. *- What role do shared bicycles play in shaping the modal split, particularly in improving connectivity to public transport for suburban commuters?*

Bicycle-sharing systems in suburban areas benefit from mutual synergy to enhance the use of both modes. The literature shows that to reach this potential, easy transferability between the two modes plays a dominant role (Kager et al., 2016; Jäppinen et al., 2013; Fishman et al., 2012). The importance of this synergy is much more dominant in suburban areas than urban areas, due to the non-competitiveness between the two modes and the dominant role of the car. In urban areas, shared bicycles compete with inner city public transport rather than complete (van Marsbergen et al., 2022; Bachand-Marleau et al., 2012; Leth et al., 2017). Shared bicycles are integrated into station-based and free-floating systems (Jorritsma et al., 2021), offering flexibility for different types of trips, including single trips from station to hub or between hubs, as well as station-to-station roundtrips.

SQ.2. *- What elements influence the usage of shared bicycle systems?*

The literature and revealed preference highlight a variety of influential factors. Public transport competitiveness with cars is a critical backbone for the effective use of shared bicycles in suburban areas, as shared bicycle potential relies on synergy with public transport in a suburban context. 50 % of the respondents recognised potential in shared bicycles, but almost always in combination with public transport. Shared bicycles as an alternative for a single bicycle ride or combined with park-and-ride facilities show negligible potential. Furthermore, private bicycles are currently often the last mile alternative, diminishing shared bicycle usage. Many current car users no longer consider public transport viable due to non-competitive travel times and the perception that public transport travel time is longer than it is in reality. Besides public transport competitiveness, good transferability, a safe and well-designed bicycle infrastructure, public familiarity of the shared bicycle system and sufficient shared bicycle availability at stations increase the potential, since low availability creates a negative perception and uncertainty.
Costs emerge as another critical factor. High costs of shared bicycles form a significant barrier to usage (Adnan et al., 2019; Ton et al., 2019). Employer involvement and shared bicycle memberships can mitigate this barrier since 65 % of the respondents open to bicycle sharing indicate doing so if the employer finances the usage and 36.7 % sees potential in periodical payments.
Car parking limitations, such as higher costs and lower parking availability, are considered important

non-bicycle-related factors when aiming for a modal shift towards bicycle sharing. Companies that introduced parking costs have a 34.7 % lower share of car commuters, showing the marginal effect on the modal shift.
The literature and survey conclude that within suburban areas, an optimal egress distance between 0.5 km and 3 km presents the greatest opportunity for shifting towards public transport and shared bicycles. Companies within this range from a public transport station thus benefit most from shared bicycles.
Shared bicycle potential is also dependent on several user demographics. Where young, high-income, highly educated male who have no driving licence or car and commute frequently show the most potential for bicycle sharing.

SQ.3. *- To what extent will commuters change their travel patterns and mode choices in response to changes in bicycle-sharing infrastructure, public transport and measures discouraging car use?*

The stated choice experiment shows that participants value an additional euro in rental costs three times worse than one extra minute of travel time for most travel time parameters, with younger and lower-income individuals being more strongly influenced by costs. Shared bicycle systems with 24-hour availability, such as the OV-Fiets, outperform one-ride systems like Donkey Republic, particularly for infrequent travellers. This analysis also shows a general preference for cars compared to public transport and shared bicycles. The interaction parameters reveal that Women are more negatively affected by public transport travel time, implying lower adaptability to shared bicycles than men.

General and persona-based simulations in Leiden en Drechtsteden translate the importance of costs to cost-related interventions, with free shared bicycles (3.6 - 4.3 %pt.) and car parking limitations (5.3 - 9.4 %pt.) showing the highest potential to reduce car use. Free shared bicycles significantly boost shared bicycle usage, while parking restrictions primarily shift users to public transport. The general simulation does not show a reduction in car share when introducing Donkey Republic instead of OV-Fiets. However, for the persona-based analysis, the OV-Fiets outweighs Donkey Republic significantly for less frequent travelling and middle-income males and thus Donkey Republic is efficient for companies with frequent commuters. Donkey Republic systems benefit from hub placement as close as possible to the company.
For suburban commuting, electric shared bicycles do not outperform regular bicycles. The simulation shows a tipping point at a 7.25 km egress distance, but at this distance, the car is so dominant (98 % share) that shared bicycle potential is diminished.
A notable constraint of these system adjustments is again the travel time ratio between public transport and car. When public transport travel time is double that of cars, the potential impact of system adjustments is five times lower compared to scenarios where the ratio is 0.8. This highlights the importance of investing in cost initiatives when public transport is somewhat competitive or investing in better quality public transport in areas where the average travel time ratio between car and public transport is high.

These sub-questions ultimately lead to the answer to the main question: *How can adjustments in the shared bike system enhance the use of public transport as the primary commuting mode, offering a viable alternative to cars in suburban areas?*

This research shows that the competitiveness of public transport with cars is the most critical factor in enhancing shared bicycle usage in suburban areas. When public transport offers travel times comparable to car commuting, usage of both public transport and shared bicycles significantly increases.
Ensuring shared bicycle availability, particularly in high-demand areas, is crucial, to ensuring the reliability of the system. The success of shared bicycles is closely tied to their seamless integration with public transport, but the potential with park-and-ride facilities or as an alternative for private bicycles is negligible.
Cost-related interventions, such as free or subsidised shared bicycles and employer involvement, effectively increase shared bicycle and public transport usage. However, while parking limitations have the greatest potential to reduce car use, they may lack equity and the overall potential for shared bicycle use.
Combining shared bicycle systems, like OV-Fiets and Donkey Republic, are most effective, with hybrid

(Donkey Republic) systems better suited for frequent travellers.

In a suburban environment, e-bicycles provide minimal additional value for longer egress distances when combined with public transport. Although faster than regular bicycles, the significant advantage of cars over public transport and shared bicycles on longer trips limit the potential of this combination in such cases.

9

Discussion

This chapter reflects on the research process, findings, and limitations. Moreover, it highlights a more thorough interpretation of the results, which also makes a relation with the literature. This chapter is followed up by Chapter 10 to sustain the reflection and limitations with recommendations.

9.1. Reflection

The model and simulation results show the maximum possible potential for shared bicycles, which should be accounted for during interpretation. Some adjustments show a shared bicycle increase potential of 10 %pt. However, this is all given that the availability of shared bicycles is assured and the public transport system can withstand the increasing demand for this mode. This does not imply that the results of this study are unfeasible or should not be implemented when optimising the shared bicycle system, but it should be noted that improving the shared bicycle system coincides with improvements in the availability issue, also accounting for the bicycle parking capacity, and considering the capacity of the current public transport system.
From an inclusivity perspective, cost initiatives raise an important point. While employers mostly cover car and public transport costs, shared bicycles are typically excluded, burdening those benefitting from them for last-mile connectivity. Including shared bicycles in transit cards or subsidising them could create a more equitable system, benefiting public transport users and commuters who are not able to rely on car travel. Paid parking policies do encourage a modal shift to public transport, but fail to address the inclusivity of shared bicycle costs. To enhance inclusivity, measures should cover the entire travel chain for all commuters, addressing that shared bicycle cost initiatives should be preferred when regarding inclusivity.

The results agree with most of the findings in the literature. The importance of costs and travel time and its negative effect on the modal share for shared bicycles and public transport is regarded as similar for both this research and the existing body of literature (Adnan et al., 2019; Montes et al., 2023; Ton et al., 2020). However, this study adds additional information on the importance of shared bicycle availability and how the potential is prone to availability issues. Furthermore, this study emphasises the importance of the quality of public transport for the potential of shared bicycles. The current body of literature comments on the synergy between transit and bicycles in less urban areas but fails to underscore the problems and conditions for this synergy in suburban areas (Shelat et al., 2018; Fishman et al., 2012).

The model contradicts the literature on sociodemographic effects. The current literature shows a preference for bicycle sharing among younger people (van Marsbergen et al., 2022; Nello-Deakin and te Brommelstroet, 2021); however, the model shows high cost-consciousness within this group, resulting in younger people not preferring the shared bicycle. This can be explained by the modelling choice for interaction with individual parameters instead of modes. Hence, the interaction of the cost parameter with younger people shows the only significant relation for this group, thus resulting in this counter-intuitive finding. Furthermore, Van Marsbergen et al. (2022) investigated the modal shift in the urban

context from inner-city transit to bicycle sharing. In contrast, this research explores the potential for bicycle sharing for suburban commuting, where the car and public transport are assumed to be free. This research showed a shift to bicycle sharing because it was a cheaper and more efficient alternative to public transport. Given this context difference, cost sensitivity for younger individuals was also found in the study by Van Marsbergen et al. 2022), since younger individuals more often opted for shared bicycles. In contrast to the urban environment, the egress distance in a suburban environment can be multiple kilometres. In contrast to the findings of Campbell et al. (2016) which highlight the potential for shared e-bikes for longer egress distances, this research shows a lower potential due to the high competitiveness of the car.
In relation to a previous study on suburban travel by Boting (2023), this study more extensively highlights the potential of bicycle sharing in a broader context for commuting trips. Boting (2023 considered the options among different types of shared mobility and found potential for electric shared bicycles for egress distances above 3 kilometres. However, this study shows that for larger last-mile distances and the costs included with shared bicycles and e-bikes, the potential for bicycle sharing is diminished due to a high willingness for car commuting (98 %). This research adds to Boting's research on the important role of public transport in complementing the shared bicycle system to compete with car commuting and limiting the potential to areas where public transport is sufficient to compete with the car.

9.2. Limitations

When interpreting this study's results on the shared bicycle and public transport potential in suburban commuting, it is important to identify and assess research limitations and their effect on research output.
The most dominant limitation of this research was the small number of respondents that completed the survey ($N = 105$). A much larger sample was necessary for bias and noise to be optimally removed from the data, which is important for the revealed behaviour and attitude and the stated preference part of the survey. The validation of the choice sets in Chapter 4 pointed out that 550 respondents would be sufficient given the previous parameters and the survey design.

Furthermore, Table 5.1 shows a dominant representation of young and higher-educated respondents in contrast to the population of South Holland. This could ensure a bias towards active modes (higher education and younger age show a preference towards bicycle sharing and public transport (Heinen and Bohte, 2014; van Marsbergen et al., 2022)). The effect of the small dataset and the bias is slightly visible in the revealed survey outcome in 5. The questions shown to the respondents depend on their previous answers. With a small dataset, some questions show low respondent rates, undermining the validity of those questions. The question regarding experienced difficulties during renting a shared bicycle only received 5 responses, making it hard to draw substantiated conclusions. A smaller dataset also makes it difficult to determine the effect of demographics on the revealed trip data.

Another point that must be addressed is the lack of revealed preference data. This study originally aimed to combine a revealed preference survey through a pilot conducted by the Zuid-Holland province and a stated preference survey. Due to delays and limitations in this pilot, the focus shifted to the stated preference to determine the quantitative effect of shared bicycle attributes. This research now uses the revealed data to identify the effect of certain measures on the current travel patterns and to show how respondents regard bicycle sharing and public transport. This ultimately gave a broad range of valuable insights on how to optimise bicycle-sharing systems.

Some limitations concerning the stated preference survey should be acknowledged. First, the number of respondents for the stated preference experiment (105) was five times lower than the efficient design suggested, resulting in less statistical power. This limitation makes it harder to detect subtle effects and introduces greater uncertainty about the validity of the estimated parameters. In addition, the small sample size increases the risk of overfitting, especially when the model is optimised with 77 parameters and interaction terms for the first optimisation step. With more respondents, the model would have a better ability to generalise and avoid fitting too closely to the sample data.

The model used is a simple but efficient MNL model, mostly due to data limitations. This model assumes the unobserved utility across the observations as independent and identically distributed, leading to correlations in unobserved utility and thus a bias in the parameter estimations (van Cranenburgh, 2023). Furthermore, the MNL stated choice survey assumes predetermined utility functions. Hence, assuming the choice behaviour to be dependent on these attributes.

The model assumed all modalities to be present to the respondent, while in reality, a major limitation of shared bicycles is the availability. Therefore, the share of public transport alternatives may be lower than the model shows. Furthermore, this biasses the model to calculate the optimal potential, while other external factors, including availability, influence public transport and shared bicycle usage too. Also, the effect of private bicycles at the work-side station is excluded from the survey, limiting the choice possibilities for the respondents. However, to exclude this alternative, the survey explores the real potential of shared bicycles.
The stated preference survey over-idealises the public transport (+ shared bicycle) options. In the simplification process of the survey, factors such as shared bicycle availability, possible transfer and waiting time for public transport are not considered or included in travel time factors. Transfer time and waiting time are perceived quite negatively (Schakenbos et al., 2016; Geržinič et al., 2023), but since the survey has to be kept comprehensive to the respondent and the focus leaned more towards bicycle sharing, these factors are incorporated in travel time.

10 Recommendations

10.1. Recommendations for Policy

The research results show valuable output that can be incorporated into policy for bicycle sharing and car-reducing policy points. This section demonstrates recommendations regarding general, more widespread policy and specific policy points for Provincie Zuid-Holland.

10.1.1. General policy points

Cost-related policy points are critical, as costs are valued three times as negatively as other attributes as the model shows. Policies such as free shared bicycles and car parking fees can significantly promote usage. A policy for employer incentives to subsidise shared bicycle sharing is recommended. Micromobility is not yet included in corporate public transport cards such as the NS business card (Nederlandse Spoorwegen, 2024b). Including micromobility in this card lowers the barrier for using and stimulates the modal shift from car to public transport + shared bicycle. Policymakers should also introduce memberships for shared bicycles. The survey shows that this measure can encourage shared bicycle usage, and when frequently used, this membership can be cost-effective and thus more appealing.
Companies should consider reducing car parking places to increase parking time and reduce availability. This intervention should align with an investment in parking for (shared) bicycles. Investing in a hub for shared bicycles is a recommended measure related to bicycle parking interventions around the office. The model output shows increasing hybrid shared bicycle usage with an optimal hub location. This policy is most effective for companies with frequent commuters

This research advises policymakers to critically assess and invest in shared bicycle availability at suburban stations, replacing some regular bicycle parking spaces with shared bicycle spaces. Reducing the options for personal second bicycles and increasing the availability of shared bicycle spaces encourages commuters to consider shared options. Important to consider is that mainly suburban stations that are well accessible by public transport benefit from this policy.
This study highlights the areas where the integration of shared bikes is most valuable. It recommends that policymakers focus on integration with public transport, considering good transferability and availability. The study also shows limited potential for shared bicycle policy on park-and-ride facilities. Although car park-and-ride locations are possible for shared bicycles, the survey results show little to no potential for this combination. Policymakers are thus discouraged from focusing on this combination and encouraged to optimise the synergy with public transport.

10.1.2. Policy for Provincie Zuid-Holland

This paragraph applies the policy recommendations specifically to the province of South Holland. This study concludes that the public transport quality forms the backbone for shared bicycle potential within commuting. An advised policy point for the Province of South Holland is to invest in better provincial public transport to stimulate better public transport coverage and connectivity in suburban areas.
Furtermore, South Holland should actively encourage companies and providers to integrate different

bicycle-sharing systems into the business public transport cards (Such as the NS business card (Nederlandse Spoorwegen, 2024b), Shuttel (shuttel, n.d.) or Gaiyo (Gaiyo, n.d.)). This integration tackles the costs for shared bicycles and enforces an employer incentive that offers shared bicycles for free, for a reduced fee or in the form of a monthly membership. The stimulation to integrate all shared micromobility systems also tackles the different people or back-to-one 24-hour systems (OV-Fiets) or hybrid single-ride systems (Donkey Republic). Since CO_2 emissions for commuter trips have been monitored for companies since July 2024, South Holland can enhance sustainable mobility for companies via these incentives in a more sustained and efficient manner.
Thirdly, the province of South Holland is advised to tackle the hub location issue on both the station side as well as the company side. Optimal hub locations in the neighbourhood of companies show enhanced potential for bicycle sharing and the province can, together with municipalities, stimulate the placement of clear hubs close to the companies. On the station side, South Holland should lobby with municipalities to invest in hubs that optimise the transfer between transit and bicycle, which aligns with the improved potential due to good transferability (Ma et al., 2020).
Fourth, South Holland is advised to initiate campaigns to gain knowledge on shared bicycles. This initiative increases familiarity with the concept. Campaigns of Zuid-Holland Bereikbaar can stimulate this by further enhancing their campaigns on offering free vouchers for shared bicycles. To optimise the effect, an integrated approach with companies is essential and the infrastructure (transferability between public transport and bicycles, hub locations) should be optimised. South Holland is advised to invest in research to optimise these hub locations and investigate stations and companies with the most potential for bicycle sharing to specify the focus of their campaign.
Lastly, South Holland is advised to promote the ”Wisselfiets” concept as a shared bicycle solution. This research highlights its potential to replace private bicycles for short, end-of-trip journeys, as the Wisselfiets is immediately available for the next commuter’s egress trip, enhancing turnover and accessibility at activity-end stations (Provincie Zuid-Holland, 2024b). This tackles the availability issue, as shared bicycles are in constant rotation, meets the outcome of this study on the potential for shared bicycles as an alternative to private bicycles and tackles the parking pressure issue in bicycle parking at stations.

10.2. Recommendations for further research

This research showed various valuable conclusions about how suburban commuter trips can undergo a modal shift to public transport and shared bicycles and what elements of shared bicycles, system adjustments, and other measures enhance this modal shift. However, this study showed some limitations that can be captured in further research.

This research used an MNL model to describe the choice behaviour. To further dive into the choice behaviour on this topic, this research suggests a mixed logit to account for independent and identically distributed errors and biased parameter values. Furthermore, this research investigated multiple alternatives including public transport. Hence, to capture this nesting effect, a mixed logit is adviced (van Cranenburgh, 2023). This model could thus optimise the model fit. In this research, respondents make 6 choices based on their designated choice sets. To account for this, a panel mixed logit is suggested (van Cranenburgh, 2023).
Also suggested is a study that monitors actual travel behaviour during a pilot study where shared bicycles are provided relatively accessible (in terms of costs or availability). This method can more accurately determine what factors regarding bicycle sharing, public transport and car-discouraging measures trigger the respondent to use shared bicycles. This research can serve as a starting point for this research by providing current knowledge on these triggers in suburban areas.

A study that aims to quantify the availability issue for shared bicycles is recommended to further investigate this. This study and the existing body of literature identify the need for the availability of shared bicycles and that this is for many a boundary for their adaptation. However, the stated preference experiment in this study fails to quantify the effect of low availability and how this affects the modal split. Hence, follow-up research on this topic is recommended. In addition, the type of membership for shared bicycles may be interesting to investigate further. This research identified the potential of memberships and highlights the cost-benefit they could offer, but thorough research into the effect of different memberships can further expand the body of literature on this topic.

Another possibility for further research is to place suburban shared bicycle-PT integration as a substitution for car trips in a broader context. This study focused on commuting trips, but other trips, such as leisure, are also worth investigating to broaden the understanding of shared bicycle potential. This study can also be performed in rural areas to investigate how the potential of shared bicycles differs from urban and suburban contexts and to maximise the potential in those areas.

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A

Influencing factors summary

Table A.1: Influencing factors and literature

Factor	Paper(s)	Relation	Effect
Costs	Adnan et al., 2019; Montes et al., 2023	Multiple studies show that the costs of using a shared bicycle negatively affect the usage rates.	-
Travel time	Ton et al., 2019	The optimal travel time for bicycle sharing between transit and work is linearly related to the egress distance. The literature concludes that a perception difference between egress distance and travel time can exist.	-
Egress distance	Bachand-Marleau et al., 2012; Fan et al., 2019; Heinen et al., 2010	The shared bicycle usage decreases within the optimal egress distance range. According to different papers, this range varies from 500 - 2000 m to 500 - 3500 m.	-
Good transferability to bicycles	Ma et al., 2020	To increase shared bicycle usage, transfer time and difficulty should be minimized. Usage rates increase when the bicycles are easily accessible from the station and thus when transfer time is minimized.	+
Availability	Brand et al., 2017; Fan et al., 2019; Heinen et al., 2010	Availability of shared bicycles on the egress side is considered an issue for the usage rates of shared bicycles on this part of the trip. Further studies are however needed on this topic.	+
Travel frequency	Barbour et al., 2019	Shown is that people with higher travel frequencies have a positive attitude towards shared bicycles and are therefore more often using them.	+
Safety perception	Fishman et al., 2012	Shown is that when commuters judge the shared bicycle as a less safe option than other modes, the usage rates decrease.	+
Station capacity	Faghih-Imani and Eluru, 2015	A high capacity of the docking or parking location for shared bicycles at a location positively influences the usage for this mode.	+
Well-designed cycling infrastructure	Leth et al., 2017	A cycle-friendly environment enhances the usage of (shared) bicycles within that area. Hence, this is considered a positive factor for bicycle sharing.	+

Flexibility of a car trip	Carse et al., 2013; Abrahamse et al., 2009	Mentioned is that the flexibility of an uni-modal car trip is for many commuters a reason to use the car and not switch to public transport and shared bicycle.	-
Habit	Lanzini and Khan, 2017	The habit of using a certain mode of transport, for example, the car, is considered a reason for a more rigid attitude towards mode changes and therefore often the adaptation of shared bicycles in a commuting trip.	+/-
Technological barrier	Jorritsma et al., 2021	Technological knowledge gaps for operating shared bicycles and usage of shared bicycle booking applications can lead to inconvenience for those users and a reason not to use shared bicycles	-
Second bicycle at station	Krizek, 2011; Teixeira et al., 2023	Having a second bicycle at a station can be a reason for current public transport users not to use a shared bicycle for the last mile. However, a shared bicycle can prevent theft and damage to private bicycles.	-
Bicycle parking proximity	Fishman et al., 2015	Important for last mile usage of shared bicycles is the proximity of a bicycle parking or a shared bicycle hub close to the destination. If there is a parking or docking location within 250 meters of the final destination, usage rates increase significantly.	+
Bicycle quality	Ma et al., 2020	The quality of the shared bicycle influences the usage rates. A positive correlation was found between the quality of the bicycles and the use of them.	+
E-bikes	Jorritsma et al., 2021; Campbell et al., 2016	Using shared e-bicycles can expand the distance for which shared bicycles are a suitable last-mile travel option.	+
Employer incentives	Ton et al., 2020; Nello-Deakin and te Brommelstroet, 2021	Employer incentives to enhance or subsidise bicycle sharing and public transport have a positive effect on modal shift	+
Gender	Böcker et al., 2020; Faghih-Imani and Eluru, 2015; Heinen and Bohte, 2014	Men are more likely to use shared bicycles than women. However, it is concluded that women do make longer trips than men when using shared bicycles.	Male (+)
Age	van Marsbergen et al., 2022	In general, younger people tend to use shared bicycles more often than older people. This finding goes hand in hand with the general better vitality of younger people.	Young (+)
Income	Fan et al., 2019; Shelat et al., 2018; Barbour et al., 2019; Nello-Deakin and te Brommelstroet, 2021	The combination of public transport and shared bicycles is more popular among lower-income groups. However, the concept of bike sharing for only the last mile is more popular under higher income levels.	High (+)
Education	Heinen and Bohte, 2014	Higher education levels generally coincide with higher incomes. Therefore the literature shows a positive correlation between higher incomes and bicycle-sharing adaptation	High (+)

Degree of urbanisation	Barbour et al., 2020	Ride-sourcing with shared bicycles is a more common phenomenon in denser urban areas where also the job density is higher. This factor however introduces the problem with suburban areas and thus the cause for this research	+
Having children	Barbour et al., 2020; Santos et al., 2013	People who have children are less likely to use bike sharing for commuting trips.	+
Vehicle ownership	Santos et al., 2013; Krygsman et al., 2004	Having a car negatively influences the willingness to use shared bicycles and public transport. For this group, it is easier to take the car, whereas groups that do not own a bicycle do not have this possibility.	-
driving licence	Eren and Uz, 2020	The same as for vehicle ownership, licence ownership also negatively influences the usage rates for bicycle sharing because of the possibility of using a car for commuting trips.	-
Comfort of the car trip	Abrahamse et al., 2009	The comfort of a car being uni-modal and flexible in departure time is for many commuters a reason to keep using the car and not switch to public transport and shared bicycles.	-
Car parking availability	Buehler, 2012; Currie and Delbosc, 2011	Parking availability for cars at the destination is of significant influence on the usage of shared bicycles. Low parking availability indicates a lower attractivity of the car and a need for alternative modes.	-
Lack of knowledge	Jorritsma et al., 2021	For shared bicycles to be used, the operator of the shared bicycles must be known to the commuter, otherwise, different, more familiar modes will be more attractive.	-
Environmental Awareness	Fishman et al., 2014; Jorritsma et al., 2021	For many users of the shared bicycle, environmental reasoning can be beneficial for shared bicycle usage. People who actively care about the environment more often leave their cars and use public transport or shared bicycles.	+
Weather	Corcoran et al., 2014	Warm and dry weather is in general a more attractive environment for bicycle usage and thus for using shared bicycles.	Warm/Dry (+)
Implementation of MaaS (Mobility as a Service)	Jorritsma et al., 2021	To optimise the integration of shared bicycles with public transport and create an easy and accessible transit-bicycle sharing combination, the potential of an integrated MaaS system can enhance this integration.	

B

Survey Design (Dutch)

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Enquête deelfietsen

Start van blok: Blok 0: Introductie

Intro Beste deelnemer,

Deze enquête is deel van een afstudeeronderzoek van de TU Delft naar het gebruik van deelfietsen in het woon-werk verkeer in Zuid-Holland. Deze vragenlijst zal inzicht geven in het woon-werk reisgedrag, de houding tegenover deelfietsen en de mogelijkheden om deelfietsen te gebruiken in combinatie met het openbaar vervoer. Wij willen aan de hand van uw antwoorden inzicht krijgen in de behoeftes van reizigers rondom de deelfiets en de uitdagingen en kansen die er zijn.

Deze enquête zal **ongeveer 10 minuten** in beslag nemen. Uw deelname aan dit onderzoek is volledig vrijwillig en u kunt elk moment stoppen. U bent vrij om persoonlijke vragen over te slaan wanneer u dat wilt. Wij zullen privacy risico's minimaliseren door nooit te vragen naar bijvoorbeeld naam, e-mail of exacte woonadres.

Door akkoord te gaan met de deelname geeft u toestemming dat de antwoorden van deze vragenlijst mogen worden gebruikt voor dit onderzoek en alleen beschikbaar zijn voor de verantwoordelijke onderzoekers. De data zal na afloop van dit onderzoek worden verwijderd.

Uw deelname wordt erg gewaardeerd!

Jorn van Steen
Afstudeerder TU Delft

0.1 Heeft u de bovenstaande informatie begrepen en gaat u akkoord met het gebruik van deze gegevens voor onderzoeksdoeleinden?

- ○ Ja
- ○ Nee

Einde blok: Blok 0: Introductie

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Start van blok: Blok 1: Reisgedrag en keuzes

1.0 Welke van de volgende vervoersmiddelen heeft u in de afgelopen maand wel eens gebruikt? Denk hierbij niet alleen aan woon-werk verkeer, maar aan alle ritten die u heeft gemaakt. U kunt meerdere antwoorden aankruisen.

- ▢ Auto
- ▢ Trein
- ▢ Bus/tram/metro
- ▢ Fiets
- ▢ Deelfiets
- ▢ Elektrische fiets
- ▢ Te voet
- ▢ Anders, namelijk: ____

Pagina-einde

Ik wil u nu vragen om alleen na te denken over de reis van huis naar uw werk. Hoe heeft u deze reis de afgelopen maand gemaakt?

1.1 Maakt u regelmatig een tussenstop onderweg naar uw werk (bijv. voor kinderen naar school brengen of de supermarkt)?

- ○ Ja
- ○ Nee

1.2 Hoevaak reist u gemiddeld <u>per week</u> naar het werk

- ○ 0 of 1 keer
- ○ 2
- ○ 3
- ○ 4
- ○ 5 of meer keren

Deze vraag weergeven:

If Als Welke van de volgende vervoersmiddelen heeft u in de afgelopen maand wel eens gebruikt? Denk hierbij niet alleen aan woon-werk verkeer, maar aan alle ritten die u heeft gemaakt. U kunt meerdere ant... q://QID75/SelectedChoicesCount is niet gelijk aan 1

Geselecteerde opties overbrengen uit "1.0"

1.3 Hoe reist u het vaakst naar werk? Reist u met meerdere vervoersmiddelen, kies dan de optie waarmee u de langste afstand heeft afgelegd.

- ○ Auto
- ○ Trein
- ○ Bus/tram/metro
- ○ Fiets
- ○ Deelfiets
- ○ Elektrische fiets
- ○ Te voet
- ○ Anders, namelijk: ____

Pagina-einde

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Deze vraag weergeven:

If Als Hoe reist u het vaakst naar werk? Reist u met meerdere vervoersmiddelen, kies dan de optie waarmee u de langste afstand heeft afgelegd. Trein is geselecteerd

And 1.0 = Trein

1.4.1 Welk vervoersmiddel gebruikt u om van huis bij de trein te komen op uw route naar het werk?

- Lopen
- Fiets
- Elektrische fiets
- Bus/tram/metro
- Auto
- Anders, namelijk: ____

Deze vraag weergeven:

If 1.4.1 = Bus/tram/metro

1.4.1.1 U heeft aangegeven met de bus, tram of metro naar de trein te gaan. Hoe gaat u vanaf huis naar de bus, tram of metro toe?

- Lopen
- Fiets
- Elektrische fiets
- Auto
- Anders, namelijk: ____

qualtrics XM

Deze vraag weergeven:

If Als Hoe reist u het vaakst naar werk? Reist u met meerdere vervoersmiddelen, kies dan de optie waarmee u de langste afstand heeft afgelegd. Trein is geselecteerd

And 1.0 = Trein

1.5.1 Welk vervoersmiddel gebruikt u om van het treinstation naar het werk te komen?

- Lopen
- Eigen fiets
- Deelfiets
- Elektrische fiets
- Bus/tram/metro
- Auto
- Anders, namelijk: ____

Deze vraag weergeven:

If Als Hoe reist u het vaakst naar werk? Reist u met meerdere vervoersmiddelen, kies dan de optie waarmee u de langste afstand heeft afgelegd. Bus/tram/metro is geselecteerd

And 1.0 = Bus/tram/metro

1.4.2 Welk vervoersmiddel gebruikt u om bij de bus, tram of metro te komen op uw route naar het werk?

- Lopen
- Fiets
- Elektrische fiets
- Trein
- Auto
- Anders, namelijk: ____

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Deze vraag weergeven:

If Als Hoe reist u het vaakst naar werk? Reist u met meerdere vervoersmiddelen, kies dan de optie waarmee u de langste afstand heeft afgelegd. Bus/tram/metro is geselecteerd

And 1.0 = Bus/tram/metro

1.5.2 Welk vervoersmiddel gebruikt u om van het bus, tram of metrostation naar het werk te komen?

- ○ Lopen
- ○ Eigen fiets
- ○ Deelfiets
- ○ Elektrische fiets
- ○ Trein
- ○ Auto
- ○ Anders, namelijk: ____

Pagina-einde

1.6 Wat is uw postcode? Geef deze aan met 4 cijfers en de eerste letter
*Voorbeeld: uw postcode is 1234AB, geef dan **1234A***

____

1.7 Welk bedrijf bent u werkzaam?
*Voorbeeld: **Bedrijf x***

____

1.7.1 Wat is de postcode van uw werk? Geef deze aan met 4 cijfers en de eerste letter. Als u het niet weet, vul dan 9999 in.
*Voorbeeld: De postcode is 1234AB, geef dan **1234A***

____

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1.7.2 In welke gemeente werkt u?

____

Deze vraag weergeven:

If Als Hoe reist u het vaakst naar werk? Reist u met meerdere vervoersmiddelen, kies dan de optie waarmee u de langste afstand heeft afgelegd. Auto is geselecteerd

And 1.0 = Auto

1.8 Is uw reis van huis naar het werk ook mogelijk met het openbaar vervoer?

- ○ Ja
- ○ Nee

Pagina-einde

Deze vraag weergeven:

If 1.8 = Ja

1.8.1 Waarom gebruikt u het openbaar vervoer niet voor uw reis naar het werk? U kunt meerdere antwoorden aankruisen

- ▢ Ik krijg het openbaar vervoer niet vergoed
- ▢ Mijn huis is te ver van een station af
- ▢ Ik vind de auto fijner
- ▢ Het werk is te ver van een station af
- ▢ De reis met het openbaar vervoer duurt te lang vergeleken met de auto
- ▢ Anders, namelijk: ____

Deze vraag weergeven:

If 1.8 = Nee

1.8.2 Waarom is de reis voor u niet mogelijk met het openbaar vervoer?

____

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Pagina-einde

1.9 Heeft u toegang tot gratis parkeren op uw werk?

- ○ Ja
- ○ Nee

1.10 Hoe zou u de autoparkeerfaciliteit beoordelen op uw werk?

- ○ Slecht, weinig plek en lang zoeken voor een plek
- ○ Matig
- ○ Gemiddeld
- ○ Redelijk
- ○ Goed, veel plek en weinig zoektijd voor een plek
- ○ Weet ik niet
- ○ Ik kan op werk niet parkeren

Einde blok: Blok 1: Reisgedrag en keuzes

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Start van blok: Blok 2: Deelfiets

In de onderstaande afbeeldingen ziet u twee voorbeelden van deelfietsen in Nederland. In de eerste afbeelding ziet u de oranje deelfiets van Donkey Republic en in de tweede afbeelding staan de NS-OV fietsen. Een deelfiets kunt u gebruiken voor een enkele rit, maar ook voor een langere periode op de dag waarna u hem terugbrengt naar het station waar u deze heeft opgehaald. In deze enquête ben ik vooral benieuwd naar mogelijkheden voor de deelfiets in uw woon-werk rit.

2.1 Welke van de volgende deelfiets systemen heeft u wel eens van gehoord of gezien? U kunt meerdere antwoorden aankruisen.

- ▢ Ik heb er nog nooit van gehoord
- ▢ Donkey Republic
- ▢ OV-Fiets
- ▢ Andere deelfietssystemen zoals Tier, Go-Sharing, Arriva fiets

Pagina-einde

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Deze vraag weergeven:

If 2.1 != Ik heb er nog nooit van gehoord

And 1.5.1 != Deelfiets

And 1.5.2 != Deelfiets

2.2.1 U heeft aangegeven bekend te zijn met de deelfiets. Denkt u dat de deelfiets mogelijkheden kan bieden voor uw reis naar het werk, bijvoorbeeld in combinatie met het openbaar vervoer? U kunt meerdere antwoorden aankruisen.

- ▢ Ja, in combinatie met het openbaar vervoer
- ▢ Ja, in combinatie met de eigen auto
- ▢ Ja, ik zou met de deelfiets van huis naar werk willen fietsen
- ▢ Nee

Deze vraag weergeven:

If 1.5.1 != Deelfiets

And 1.5.2 != Deelfiets

2.2.2 U gebruikt op dit moment de deelfiets niet. Wat zijn voor u de redenen om de deelfiets niet te gebruiken? U kunt meerdere antwoorden aankruisen.

- ▢ Ze zijn niet beschikbaar voor mijn route van huis naar werk
- ▢ Ze zijn in theorie beschikbaar, maar te vaak al uitgeleend
- ▢ Ik ervaar moeilijkheden bij het boeken of het huren van een deelfiets
- ▢ Ik heb geen zin om te fietsen na een werkdag, dus pak liever een ander vervoersmiddel
- ▢ Ik vind de deelfiets te duur
- ▢ Ik werk dichtbij een station, dus lopen is handiger
- ▢ Ik werk te ver van een station af, dus de deelfiets is geen optie
- ▢ Ik weet niet hoe de deelfiets werkt
- ▢ De deelfiets staat op een onhandige plek op het station
- ▢ Ik heb al een eigen fiets bij het station staan
- ▢ Ik ervaar een andere belemmering, namelijk:

____

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Deze vraag weergeven:

If 2.2.2 = Ik ervaar moeilijkheden bij het boeken of het huren van een deelfiets

2.2.3 U heeft aangegeven dat u moeilijkheden ervaart bij het boeken of huren van de deelfiets. Welke moeilijkheden ervaart u? U kunt meerdere antwoorden aankruisen.

- ▢ De app waarmee ik moet reserveren is complex
- ▢ Het kost mij veel extra tijd om een deelfiets te huren
- ▢ Ik weet niet hoe de app werkt
- ▢ Ik wil geen nieuwe app installeren hiervoor
- ▢ Ik heb geen telefoon
- ▢ anders, namelijk: ____

Pagina-einde

Deze vraag weergeven:

If 2.2.1 != Nee

2.3 Hieronder wordt een lijst gegeven met maatregelen en kenmerken van de deelfiets. Bij welke van deze maatregelen overweegt u de deelfiets te gebruiken voor het laatste stuk van de woon-werk reis? U kunt meerdere antwoorden aankruisen.

- ▢ De deelfiets wordt gratis
- ▢ De deelfiets wordt in een abonnement gestopt, waardoor ik 1x per maand een voordelig vast bedrag betaal en daarmee altijd gebruik kan maken van de deelfiets
- ▢ De deelfiets wordt vergoed door mijn werkgever
- ▢ Er worden tegen een laag tarief e-bikes aangeboden, zodat u sneller van het station naar werk kan reizen
- ▢ Er wordt betaald parkeren ingevoerd bij uw werk
- ▢ Er worden een flink aantal auto-parkeerplekken weggehaald, waardoor het moeilijker wordt om te parkeren
- ▢ U kunt de deelfiets altijd en makkelijk parkeren op uw werk
- ▢ anders, namelijk: ____

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Deze vraag weergeven:

If 1.0 = Deelfiets

2.4 U heeft aangegeven de deelfiets wel eens te gebruiken, waarom doet u dit? U kunt meerdere antwoorden aankruisen.

- ▢ Het is gratis voor mij (vergoeding of gratis Donkey Republic fiets)
- ▢ Het biedt voor mij een goede verbinding tussen het station en het werk
- ▢ Parkeren bij mijn werk kan lastig zijn
- ▢ Het is eenvoudig een fiets te pakken en daarmee het laaste stuk af te leggen
- ▢ Ik had geen eigen fiets op het station staan
- ▢ Het alternatieve openbaar vervoer was niet goed genoeg
- ▢ Ik doe dit voor de gezondheid
- ▢ Ik heb de deelfiets ergens anders voor gebruikt, namelijk ____

2.5 Hoe veilig vind ik de wegen om te fietsen rondom mijn werk?

- ○ Veilig
- ○ Redelijk veilig
- ○ Neutraal
- ○ Redelijk onveilig
- ○ Onveilig
- ○ Weet ik niet

Einde blok: Blok 2: Deelfiets

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Start van blok: Blok 3.1: Inleiding SP

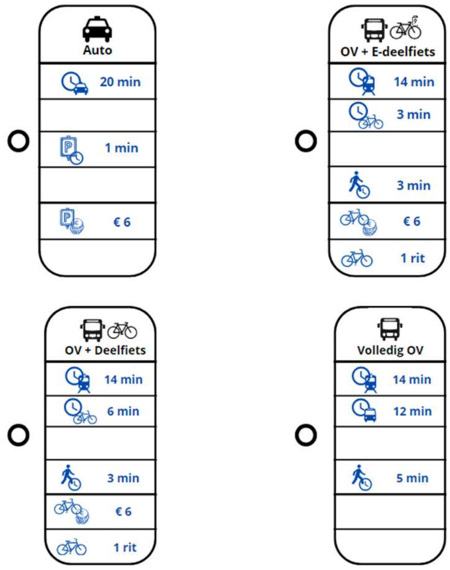
In dit deel van de enquête krijgt u om 6 keer een keuze te maken om naar werk te reizen. Elke keer zijn er 4 mogelijkheden, die verschillen in reistijd, zoektijd voor een parkeerplaats, looptijd, parkeerkosten, huurkosten van de deelfiets en het type abonnement voor de deelfiets. Ik wil u vragen altijd de optie te kiezen die u het meest aanspreekt.

Bij deze situaties moet u uitgaan van de volgende omstandigheden:

- Het is **niet mogelijk** de reis met alleen de fiets of te voet af te leggen.
- Het is **droog** en de temperatuur is **goed.**
- U gaat het aantal keer naar kantoor per week zoals u **in deze enquête** heeft aangegeven.
- Het grootste deel van de reis voor **auto en openbaar vervoer** wordt vergoed door de werkgever en is dus **gratis**.
- De kosten voor parkeren en het nemen van een deelfiets zullen variëren.
- U kunt kiezen tussen 4 reisopties, deze zijn voor u **allemaal beschikbaar**:
  - De auto
  - Het openbaar vervoer (trein) met **deelfiets**
  - Het openbaar vervoer (trein) met **elektrische deelfiets**
  - Een rit volledig met het openbaar vervoer (trein + bus)
- De kosten zijn in **euro per dag.**
  U ziet hieronder uitleg van de icoontjes die gebruikt worden bij de alternatieven.

Het type abonnement is opgesplitst in **enkele rit,** waarbij je de fiets in je bezit hebt voor een ritje en **24 uur,** waarbij je de fiets voor de hele dag bij je kan houden.

U ziet hieronder een keuzevoorbeeld. Wanneer een vakje wit is bij een alternatief, betekent dit dat dit attribuut niet relevant is voor het alternatief en dus op **0** gesteld kan worden:



Einde blok: Blok 3.1: Inleiding SPStart van blok: Blok 3.2: Stated Preference Blok 1

Hiertussen worden gerandomiseerd een set van 6 keuzemogelijkheden getoond zoals te zien in de figuur hierboven

Einde blok: Blok 3.3: Stated Preference Blok 2

Start van blok: Blok 3.4: Validatie

3.4.1 Speelde er een bepaalde factor mee tijdens het maken van je keuze? Zo ja, welke? (Optioneel)

____

Einde blok: Blok 3.4: Validatie

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Start van blok: Blok 4: Demographics

4.1 Wat is uw geslacht?

- Man
- Vrouw
- Niet-binair/derde geslacht of anders
- Ik zeg dat liever niet

4.2 Wat is uw leeftijd?

- Jonger dan 18
- 18 - 30
- 30 - 45
- 45 - 60
- 60 jaar of ouder

4.3 Heeft u een autorijbewijs in uw bezit?

- Ja
- Nee

4.4 Heeft u een auto in uw bezit?

- Ja
- Nee

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4.5 Wat is het hoogste opleidingsniveau dat u heeft afgerond?

- Niets, basisschool of middelbare school
- MBO
- HBO
- WO
- Zeg ik liever niet

4.6 Wat is uw bruto jaarloon?

- €0 tot €20.000
- €20.000 tot €30.000
- €30.000 tot €45.000
- €45.000 tot €60.000
- €60.000 tot €80.000
- meer dan €80.000
- Zeg ik liever niet

Einde blok: Blok 4: Demographics

C

Attribute levels choice set

This appendix shows the attribute levels for the 12 choice set as presented to the respondents in the survey. The block indicates to which set of 6 choice sets the set belongs.

Attribute	1	2	3	4	5	6	7	8	9	10	11	12
Travel time car [min]	40	40	20	40	40	20	40	40	40	20	20	40
Parking time car [min]	1	5	5	1	5	1	1	1	5	5	1	5
Parking costs car [€]	0	0	6	0	6	0	6	6	0	0	6	6
Travel time PT [min]	14	28	28	28	14	14	28	14	14	14	14	14
Shared bicycle egress time [min]	6	6	12	9	6	6	9	9	6	9	9	6
Shared bicycle walk time [min]	3	3	3	1	5	5	5	1	5	1	1	3
Shared bicycle costs [€]	3	3	0	0	0	3	3	6	6	0	0	6
Shared bicycle system	0	0	1	1	0	0	1	1	1	0	0	0
Shared e-bike egress time [min]	3	9	3	9	3	9	9	6	9	6	3	3
Shared e-bike walk time [min]	1	5	5	5	6	1	3	1	1	5	1	6
shared e-bike costs [€]	0	0	0	0	0	0	1	1	0	0	0	0
Shared e-bike system	1	1	1	0	1	1	1	0	1	1	0	0
Public transport egress time [min]	9	6	12	6	12	9	12	12	6	12	12	12
Public transport walk time [min]	5	1	1	3	1	5	1	5	3	1	3	5
Block	1	2	1	1	1	1	2	1	2	2	2	2

D
Dataset survey

D.1. Travel behaviour

Table D.1: Mode choice data

Question	Answers	Abs. number	Percentage
Modes of Transport used in the past month	Car	97	92.4 /%
	Train	76	72.4 %
	Bus/Tram/Metro	70	66.7 %
	Bicycle	85	81.0 %
	Shared-Bicycle	17	16.2 %
	E-Bicycle	26	24.8 %
	By foot	87	82.9 %
	Else	12	11.4 %
Do you have an additional stop on your way to work?	Yes	30	28.6 %
	No	75	71.4 %
Main mode for commuting	Car	37	35.2
	Train	27	25.7
	Bus/Tram/Metro	11	22.9
	Bicycle	24	10.5
	Shared-Bicycle	0	0.0 %
	E-Bicycle	4	3.8
	By foot	0	0.0 %
	Else	2	1.9
Access mode to train	By Foot	7	25.0 %
	Bicycle	14	50.0 %
	E-Bicycle	2	7.1 %
	Bus/Tram/Metro	1	3.6 %
	Car	2	7.1 %
	Else	1	3.6 %
Access mode to Bus/tram/metro if this is the access mode for train	By Foot	1	100.0 %
	Bicycle	0	0.0 %
	E-Bicycle	0	0.0 %
	Car	0	0.0 %
	Else	0	0.0 %
Egress mode from train to work	By Foot	20	74.1 %

	Bicycle	1	3.7 %
	Shared bicycle	1	3.7 %
	E-Bicycle	0	0.0 %
	Bus/Tram/Metro	4	14.8 %
	Car	0	0.0 %
	Else	1	3.7 %
Access mode to Bus/-Tram/Metro	By Foot	7	63.6 %
	Bicycle	4	36.4 %
	E-Bicycle	0	0.0 %
	Bus/Tram/Metro	0	0.0 %
	Car	0	0.0 %
	Else	0	0.0 %
Egress mode from bus/-tram/metro to work	By Foot	11	100.0 %
	Bicycle	0	0.0 %
	Shared bicycle	0	0.0 %
	E-Bicycle	0	0.0 %
	Train	0	0.0 %
	Car	0	0.0 %
	Else	0	0.0 %

D.2. Attitude towards parking and public transport

Question	**Answers**	**Abs. number**	**Percentage**
Trip possible by public transport	Yes	27	81.8 %
	No	6	18.2 %
If yes, why do you not use it?	No compensation	2	7.4 %
	Access distance is too large	3	11.1 %
	I prefer the car	10	37.0 %
	Egress distance is too large	5	18.5 %
	The trip via public transport is too long compared to the car	18	66.7 %
Is free parking available at work	Yes	71	67.6 %
	No	34	32.4 %
Rating parking facility	Bad	7	6.7 %
	Mediocre	9	8.6 %
	Average	5	4.8 %
	Sufficient	15	14.2 %
	Good	42	40.0 %
	I would not know	19	18.1 %
	I cannot park at my office	8	7.6 %

Table D.2: Public transport attitude and parking data

D.3. Knowlegde and Attitude

Table D.3: Public transport attitude and parking data

Question	Answers	Abs. number	Percentage [%]
Which shared bicycle system have you seen or heard of?	None	4	3.8
	Donkey Republic	29	27.6
	OV-Fiets	101	96.2
	Some other bicycle sharing system	42	40.0
Is the shared bicycle a possibility for you?	Yes, with public transport	44	44.0
	Yes, in combination with the own car	5	5.0
	Yes, for the whole home-work journey	3	3.0
	No	54	54.0
Reasons not to use the shared bicycle	Not available	28	26.9
	Available, but often in use	6	5.8
	Difficulties renting shared bicycles	5	4.8
	Prefer not to cycle after work	5	4.8
	Too expensive	20	19.2
	I work close to a station, so I walk	33	31.7
	I work too far from a station, so no option	8	7.7
	I do not know how it works	8	7.7
	They are located at an unlogical location	4	3.8
	I have my private bicycle at a station	14	13.5
	Other	32	30.8
Which difficulties do you experience?	The application is complex	0	0.0
	It takes a lot of time to rent a shared bicycle	3	60.0
	I do not know how the application works	2	40.0
	I do not want a new app for this	0	0.0
	I do not own a phone	1	20.0
	Else	1	20.0
With what measures would you consider a shared bicycle	Free shared bicycles	30	61.2
	Monthly membership	18	36.7
	Subsidised by employer	32	65.3
	Offering faster shared e-bicycles	10	20.4
	Paid parking at work	7	14.3
	Large reduction of parking space	7	14.3
	Easy parking at work for shared bicycles	16	32.7
	Else	9	18.4
Why do you use the shared bicycle?	It is free	3	17.6
	It offers a good connection between station and work	7	41.2
	Parking by car is difficult	3	17.6
	It is easy to take a shared bicycle	9	52.9
	I do not have a private bicycle at the station	8	47.1

	The alternative public transport does not suffice	7	41.2
	I do it for health reasons	2	11.8
	Else	1	5.9
Rating of cycling safety	Safe	38	36.2
	Quite safe	47	44.8
	Neutral	9	8.6
	Quite unsafe	4	3.8
	Unsafe	3	2.9
	I do not know	4	3.8

D.4. Socio-demographics

Table D.4: Socio-demographics

Demographic	Category	Abs. number	Percentage
Age	18 -	0	0.0 %
	18 - 30	52	49.5 %
	30 - 45	13	12.4 %
	45 - 60	32	30.5 %
	60 +	8	7.6 %
Gender	Male	58	55.2 %
	Female	47	44.8 %
	Non-Binary / other	0	0.0 %
	Rather not say	0	0.0 %
Income	€0 - €20.000	24	22.9 %
	€20.000 - €30.000	7	6.7 %
	€30.000 - €45.000	22	21.0 %
	€45.000 - €60.000	12	11.4 %
	€60.000 - €80.000	8	7.6 %
	€80.000 +	19	18.1 %
	Rather not say	13	12.4 %
Drivers licence	Yes	101	96.2 %
	No	4	3.8 %
Car possession	Yes	70	66.7 %
	No	35	33.3 %
Education	Primary school or high school	3	2.8 %
	MBO	12	11.1 %
	HBO	31	28.7 %
	WO	59	54.6 %
	Rather not say	0	0.0 %
Travel frequency to work	0 to 1 times	6	5.7 %
	2 times	21	20.0 %
	3 times	27	25.7 %
	4 times	27	25.7 %
	more than 5 times	24	22.9 %

E

Tables for model specification and socio-demographics

E.1. Tables for merging socio-demographic groups

This section covers in-depth the analysis of merging socio-demographic groups used to optimise the MNL model. Visualized in the tables are the Chi-squared test statistics among each demographic group where red text represents a Chi-squared value below the threshold of 7.84, indicating statistically similar behaviour. Categories that show multiple tables, such as age and income, underwent a merging process to create fewer groups that still capture all the behavioural differences.

E.1.1. Age

Table E.1: Chi-squared values among age groups

	18-30	30-45	45-60	60+
18-30	x	15.46	16.01	8.08
30-45	15.46	x	8.38	4.61
45-60	16.01	9.22	x	5.30
60+	8.08	4.61	5.30	x

	18-30	30-45	45+
18-30	x	15.46	16.05
30-45	15.46	x	8.04
45+	16.05	8.04	x

E.1.2. Education level

Table E.2: Table with values.

	Elow	Emid	Ehigh
Elow	x	9.01	46.37
Emid	9.01	x	22.64
Ehigh	46.37	22.64	x

E.1.3. Travel frequency

Table E.3: Chi-squared values among different travel frequencies

	0 or 1	2	3	4	5+
0 or 1	x	4.72	12.89	7.98	13.59
2	4.72	x	8.04	6.4	15.01
3	12.89	8.04	x	4.29	9.92
4	7.98	6.4	4.29	x	4.71
5	13.59	15.01	9.92	4.71	x

	0, 1 or 2	3	4 or 5+
0, 1 or 2	x	13.23	17.18
3	13.23	x	8.34
4 or 5+	17.18	8.34	x

E.1.4. Main mode in revealed preference

Table E.4: Chi-squared values among different modalities in the revealed preference

	Car	Train	BTM	Bike
Car	x	51.06	32.19	42.27
Train	51.06	x	7.03	6.68
BTM	32.19	7.03	x	16.17
Bike	42.27	6.68	16.17	x

	Car	PT	Bike
Car	x	64.77	42.27
PT	64.77	x	11.57
Bike	42.27	11.57	x

E.1.5. Income

Table E.5: Chi-squared values among income groups in the revealed preference

	<20	2030	3045	4560	6080	80+
<20	x	11.12	9.8	4.31	19.06	8.62
2030	11.12	x	12.27	5.98	3.43	4.74
3045	9.8	12.27	x	1.56	8.03	3.4
4560	4.31	5.98	1.56	x	5.34	0.57
6080	19.06	3.43	8.03	5.34	x	3.89
80+	8.62	4.74	3.4	0.57	3.89	x

	<20	2030	3060	6080	80+
<20	x	11.12	9.38	19.06	8.62
2030	11.12	x	10.96	3.43	4.74
3060	9.38	10.96	x	7.88	2.38
6080	19.06	3.43	7.88	x	3.89
80+	8.62	4.74	2.38	3.89	x

	<20	2030	3060	60+
<20	x	11.12	9.38	15.95
2030	11.12	x	10.96	4.56
3060	9.38	10.96	x	5.53
60+	15.95	4.56	5.53	x

E.2. Interaction effects

Table E.6: Travel Time by Car

Travel time car Sociodemographic	Estimate	P-value
Male	-0.021	0.000
Female	-0.038	0.000
Car	-0.008	0.123
No Car	-0.067	0.000
Age, Young	-0.037	0.000
Age, Middle	-0,013	0,061
Age, Old	-0.015	0.003
Education, Low	0.002	0.762
Education, Middle	-0.015	0.005
Education, High	-0.053	0.000
Frequency, Low	0.045	0.128
Frequency, Middle	0.072	0.012
Frequency, High	0.083	0.003
Income, Low	-0.009	0.563
Income, Middle 1	0.021	0.205
Income, Middle 2	0.021	0.111
Income, High	0.028	0.030
Main Mode, Car	0.076	0.023
Main Mode, PT	0.004	0.907
Main Mode, Bicycle	0.029	0.393

Table E.7: Travel time PT

Travel time PT Sociodemographic	Estimate	P-value
Male	-0.011	0.155
Female	-0.043	0.000
Car	-0.060	0.000
No Car	0.027	0.032
Age, Young	0.001	0.865
Age, Middle	-0.034	0.001
Age, Old	-0.031	0.000
Education, Low	-0.059	0.000
Education, Middle	-0.031	0.000
Education, High	0.022	0.016
Frequency, Low	-0.044	0.320
Frequency, Middle	-0.077	0,079
Frequency, High	-0.093	0.030
Income, Low	0.015	0.481
Income, Middle 1	-0.031	0.212
Income, Middle 2	-0.030	0.118
Income, High	-0.040	0.044
Main Mode, Car	-0.114	0.032
Main Mode, PT	-0.012	0.820
Main Mode, Bicycle	-0.042	0.433

Table E.8: Egress travel tike

Egress travel time Sociodemographic	Estimate	P-value
Male	-0.020	0.090
Female	-0.045	0.000
Car	-0.076	0.000
No Car	0.022	0.106
Age, Young	0.019	0.171
Age, Middle	-0.064	0.005
Age, Old	-0.039	0.011
Education, Low	-0.104	0.000
Education, Middle	-0.038	0.024
Education, High	0.044	0.001
Frequency, Low	-0.119	0.023
Frequency, Middle	-0.154	0.003
Frequency, High	-0.189	0.000
Income, Low	0.015	0.661
Income, Middle 1	-0.098	0.025
Income, Middle 2	-0.035	0.301
Income, High	-0.074	0.069
Main Mode, Car	-0.132	0.023
Main Mode, PT	0.083	0.157
Main Mode, Bicycle	0.008	0.894

Table E.9: Walking time

Walking time Sociodemographic	Estimate	P-value
Male	-0.011	0.632
Female	-0.079	0.002
Car	-0.117	0.000
No Car	0.073	0.006
Age, Young	0.034	0.262
Age, Middle	-0.083	0.103
Age, Old	-0.039	0.246
Education, Low	-0.161	0.003
Education, Middle	-0.030	0.424
Education, High	0.079	0.008
Frequency, Low	-0.154	0.106
Frequency, Middle	-0.224	0.018
Frequency, High	-0.207	0.023
Income, Low	0.028	0.711
Income, Middle 1	-0.106	0.322
Income, Middle 2	-0.113	0.141
Income, High	-0.164	0.038
Main Mode, Car	0.183	0.129
Main Mode, PT	-0.101	0.390
Main Mode, Bicycle	-0.052	0.663

Table E.10: Parking time

Parking time Sociodemographic	Estimate	P-value
Male	-0.115	0.002
Female	-0.024	-0.472
Car	-0.117	0.003
No Car	-0.283	0.000
Age, Young	-0.148	0.001
Age, Middle	-0.054	0.373
Age, Old	-0.010	0.813
Education, Low	0.151	0.008
Education, Middle	0.045	0.320
Education, High	-0.260	0.000
Frequency, Low	0.256	0.440
Frequency, Middle	0.392	0.229
Frequency, High	0.513	0.111
Income, Low	-0.136	0.277
Income, Middle 1	-0.039	0.795
Income, Middle 2	0.136	0.277
Income, High	0.140	0.195
Main Mode, Car	0.410	0.071
Main Mode, PT	-0.171	0.048
Main Mode, Bicycle	-0.018	0.940

Table E.11: Parking costs

Parking costs Sociodemographic	Estimate	P-value
Male	-0.089	0.002
Female	-0.022	0.440
Car	0.070	0.031
No Car	-0.240	0.000
Age, Young	-0.135	0.000
Age, Middle	0.039	0.455
Age, Old	-0.012	0.732
Education, Low	0.080	0.091
Education, Middle	0.041	0.272
Education, High	-0.220	0.000
Frequency, Low	-0.027	0.888
Frequency, Middle	0.207	0.229
Frequency, High	0.294	0.078
Income, Low	-0.249	0.047
Income, Middle 1	-0.020	0.876
Income, Middle 2	0.073	0.411
Income, High	0.316	0.091
Main Mode, Car	1.471	0.000
Main Mode, PT	1.119	0.000
Main Mode, Bicycle	1.154	0.000

Table E.12: Shared bicycle costs

Shared bicycle costs **Sociodemographic**	**Estimate**	**P-value**
Male	-0.110	0.001
Female	-0.091	0.006
Car	-0.058	0.062
No Car	-0.157	0.000
Age, Young	-0.279	0.000
Age, Middle	0.008	0.888
Age, Old	0.047	0.239
Education, Low	-0.193	0.015
Education, Middle	-0.015	0.746
Education, High	-0.043	0.291
Frequency, Low	2.129	0.000
Frequency, Middle	2.229	0.000
Frequency, High	2.248	0.000
Income, Low	-0.431	0.002
Income, Middle 1	-0.021	0.863
Income, Middle 2	-0.202	0.022
Income, High	0.012	0.885
Main Mode, Car	-0.123	0.076
Main Mode, PT	-0.230	0.002
Main Mode, Bicycle	0.200	0.001

Table E.13: System

System **Sociodemographic**	**Estimate**	**P-value**
Male	0.210	0.055
Female	-0.107	0.361
Car	-0.287	0.008
No Car	0.48	0.000
Age, Young	0.196	0.133
Age, Middle	0.316	0.123
Age, Old	-0.351	0.020
Education, Low	-0.417	0.047
Education, Middle	-0.068	0.670
Education, High	0.463	0.000
Frequency, Low	0.208	0.629
Frequency, Middle	0.086	0.839
Frequency, High	-0.562	0.017
Income, Low	0.328	0.324
Income, Middle 1	0.516	0.023
Income, Middle 2	-0.426	0.197
Income, High	-0.365	0.284
Main Mode, Car	0.040	0.962
Main Mode, PT	0.800	0.328
Main Mode, Bicycle	1.016	0.217

F

Scenario analysis personas

F.1. Persona analysis Drechtsteden

Table F.1: Effect of system adjustments on modal split Sander

System adjustment	Car	PT + Shared bicycle	PT + Shared E-bicycle	PT only
Base scenario	16.9	63.7	10.3	9.1
Free Shared Bicycle	6.8 **-10.1**	85.4 **+21.7**	4.2 **-6.1**	3.6 **-5.5**
Donkey Republic	42.1 **+25.2**	23.2 **-40.5**	12.1 **+1.8**	22.6 **+13.5**
Donkey Republic Improved Hub Location	28.1 **+11.2**	35.8 **-27.9**	20.9 **+10.6**	15.1 **+6.0**
Paid Car Parking	7.7 **-9.2**	70.8 **+7.1**	11.5 **+1.2**	10.1 **+1.0**
E-Bicycle Same Price	9.1 **-7.8**	34.2 **-29.5**	51.9 **+41.6**	4.9 **-4.2**
Combination 1 and 5	2.9 **-14.0**	89.0 **+25.3**	4.3 **-6.0**	3.8 **-5.3**

Table F.2: Effect of system adjustments on modal split Marieke

System adjustment	Car	PT + Shared bicycle	PT + Shared E-bicycle	PT only
Base scenario	96.7	0.5	0.5	2.3
Free Shared Bicycle	96.6 **-0.1**	0.6 **+0.1**	0.5 **+0.0**	2.3 **+0.0**
Donkey Republic	95.7 **-1.0**	0.9 **+0.4**	1.1 **+0.6**	2.3 **+0.0**
Donkey Republic Improved Hub Location	95.6 **-1.1**	0.9 **+0.4**	1.2 **+0.7**	2.3 **+0.0**
Paid Car Parking	94.9 **-1.8**	0.8 **+0.3**	0.8 **+0.3**	3.6 **+1.3**
E-Bicycle Same Price	96.4 **-0.3**	0.5 **+0.0**	0.7 **+0.2**	2.3 **+0.0**
Combination 1 and 5	94.7 **-2.0**	1.0 **+0.5**	0.8 **+0.3**	3.6 **+1.3**

Table F.3: Effect of system adjustments on modal split Anton

System adjustment	Car	PT + Shared bicycle	PT + Shared E-bicycle	PT only
Base scenario	89.4	6.6	3.5	0.5
Free Shared Bicycle	85.2 **-4.2**	10.9 **+4.3**	3.4 **-0.1**	0.5 **+0.0**
Donkey Republic	98.1 **+8.7**	0.7 **-5.9**	0.6 **-2.9**	0.5 **+0.0**
Donkey Republic Improved Hub Location	96.2 **+6.8**	1.7 **-4.9**	1.6 **-1.9**	0.5 **+0.0**
Paid Car Parking	84.2 **-5.2**	9.8 **+3.2**	5.3 **+1.8**	0.7 **+0.2**
E-Bicycle Same Price	84.0 **-5.4**	6.2 **-0.4**	9.3 **+5.8**	0.5 **+0.0**
Combination 1 and 5	78.5 **-10.9**	15.9 **+9.3**	4.9 **+1.4**	0.7 **+0.2**

Table F.4: Effect of system adjustments on modal split Joris

System adjustment	Car	PT + Shared bicycle	PT + Shared E-bicycle	PT only
Base scenario	30	27.9	11.2	31
Free Shared Bicycle	28.1 **-1.9**	32.5 **+4.6**	10.5 **-0.7**	29 **-2**
Donkey Republic	27.9 **-2.1**	29.8 **+1.9**	13.5 **+2.3**	28.8 **-2.2**
Donkey Republic Improved Hub Location	27.7 **-2.3**	29 **+1.1**	14.7 **+3.5**	28.6 **-2.4**
Paid Car Parking	21.3 **-8.7**	31.3 **+3.4**	12.6 **+1.4**	34.8 **+3.8**
E-Bicycle Same Price	28.4 **-1.6**	26.4 **-1.5**	15.9 **+4.7**	29.3 **-1.7**
Combination 1 and 5	19.8 **-10.2**	36.2 **+8.3**	11.7 **+0.5**	32.3 **+1.3**

Table F.5: Effect of system adjustments on modal split Maddy

System adjustment	Car	PT + Shared bicycle	PT + Shared E-bicycle	PT only
Base scenario	89.4	1.6	0.5	8.5
Free Shared Bicycle	87.5 **-1.9**	3.7 **+2.1**	0.5 **0**	8.4 **-0.1**
Donkey Republic	87.3 **-2.1**	2.6 **+1.0**	1.8 **+1.3**	8.3 **-0.2**
Donkey Republic Improved Hub Location	87.2 **-2.2**	2.5 **+0.9**	1.9 **+1.4**	8.3 **-0.2**
Paid Car Parking	84.2 **-5.2**	2.4 **+0.8**	0.7 **+0.2**	12.7 **+4.2**
E-Bicycle Same Price	87.7 **-1.7**	1.6 **+0.0**	2.4 **+1.9**	8.4 **-0.1**
Combination 1 and 5	81.5 **-7.9**	5.5 **+3.9**	0.7 **+0.2**	12.3 **+3.8**

F.2. Persona analysis Leiden

Table F.6: Effect of system adjustments on modal split Sander

System adjustment	Car	PT + Shared bicycle	PT + Shared E-bicycle	PT only
Base scenario	11.6	48.3	9.8	30.3
1 - Free shared bicycle	5.4 **-6.2**	75.7 **+27.4**	4.6 **-5.2**	14.2 **-16.1**
2 - Donkey Republic	17.6 **+6.0**	21.1 **-27.2**	15.5 **+5.7**	45.8 **+15.5**
3 - Donkey Republic improved hub location	16.6 **+5.0**	23.2 **-25.1**	17.0 **+7.2**	43.3 **+13.0**
4 - Paid car parking	5.1 **-6.5**	51.8 **+3.5**	10.5 **+0.7**	32.5 **+2.2**
5 - E-bicycle same price	6.4 **-5.2**	26.6 **-21.7**	50.4 **+40.6**	16.7 **-13.6**
6 - Combination 1 and 5	2.3 **-9.3**	78.2 **+29.9**	4.8 **-5.0**	14.7 **-15.6**

Table F.7: Effect of system adjustments on modal split Marieke

System adjustment	Car	PT + Shared bicycle	PT + Shared E-bicycle	PT only
Base scenario	90.6	1.3	1.7	6.4
1 - Free shared bicycle	90.3 **-0.3**	1.7 **+0.4**	1.7 **+0.0**	6.4 **+0.0**
2 - Donkey Republic	87.6 **-3.0**	2.4 **+1.1**	3.8 **+2.1**	6.2 **-0.2**
3 - Donkey Republic improved hub location	87.5 **-3.1**	2.5 **+1.2**	3.9 **+2.2**	6.2 **-0.2**
4 - Paid car parking	85.9 **-4.7**	2.0 **+0.7**	2.5 **+0.8**	9.6 **+3.2**
5 - E-bicycle same price	89.8 **-0.8**	1.3 **+0.0**	2.5 **+0.8**	6.3 **-0.1**
6 - Combination 1 and 5	85.4 **-5.2**	2.5 **+1.2**	2.5 **+0.8**	9.5 **+3.1**

Table F.8: Effect of system adjustments on modal split Anton

System adjustment	Car	PT + Shared bicycle	PT + Shared E-bicycle	PT only
Base scenario	60.6	19.7	13.3	6.5
1 - Free shared bicycle	52.8 **-7.8**	30.0 **+10.3**	11.6 **-1.7**	5.6 **-0.9**
2 - Donkey Republic	79.9 **+19.3**	5.2 **-14.5**	6.4 **-6.9**	8.5 **+2.0**
3 - Donkey Republic improved hub location	78.4 **+17.8**	6.0 **-13.7**	7.3 **-6.0**	8.4 **+1.9**
4 - Paid car parking	49.3 **-11.3**	25.3 **+5.6**	17.1 **+3.8**	8.3 **+1.8**
5 - E-bicycle same price	48.8 **-11.8**	15.9 **-3.8**	30.1 **+16.8**	5.2 **-1.3**
6 - Combination 1 and 5	41.4 **-19.2**	37.2 **+17.5**	14.4 **+1.1**	7.0 **+0.5**

Table F.9: Effect of system adjustments on modal split Joris

System adjustment	Car	PT + Shared bicycle	PT + Shared E-bicycle	PT only
Base Scenario	27.1	27.8	13.9	31.2
1 - Free Shared Bicycle	25.4 **-1.7**	32.3 **+4.5**	13.0 **-0.9**	29.3 **-1.9**
2 - Donkey Republic	25.1 **-2.0**	28.1 **+0.3**	17.8 **+3.9**	29.0 **-2.2**
3 - Donkey Republic Improved Hub Location	24.7 **-2.4**	28.6 **+0.8**	18.1 **+4.2**	28.6 **-2.6**
4 - Paid Car Parking	19.3 **-7.8**	30.3 **+2.5**	15.2 **+1.3**	35.2 **+4**
5 - E-Bicycle Same Price	25.3 **-1.8**	26.0 **-1.8**	19.5 **+5.6**	29.2 **-2**
6 - Combination 1 and 5	17.9 **-9.2**	35.1 **+7.3**	14.2 **-0.3**	32.7 **+1.5**

Table F.10: Effect of system adjustments on modal split Maddy

System adjustment	Car	PT + Shared bicycle	PT + Shared E-bicycle	PT only
Base Scenario	73.9	3.8	1.5	20.8
1 - Free Shared Bicycle	70.2 **-3.7**	8.7 **+4.9**	1.4 **-0.1**	19.8 **-1.0**
2 - Donkey Republic	69.4 **-4.5**	5.7 **+1.9**	5.4 **+3.9**	19.5 **-1.3**
3 - Donkey Republic Improved Hub Location	69.2 **-4.7**	5.8 **+2.0**	5.6 **+4.1**	19.5 **-1.3**
4 - Paid Car Parking	64.3 **-9.6**	5.3 **+1.5**	2.0 **+0.5**	28.6 **+7.8**
5 - E-Bicycle Same Price	69.8 **-4.1**	3.6 **-0.2**	6.9 **+5.4**	19.7 **-1.1**
6 - Combination 1 and 5	59.8 **-14.1**	11.7 **+7.9**	1.9 **+0.4**	26.6 **+5.8**