2024

Explaining Access Mode Choice for Passengers and Personnel travelling to Schiphol Airport

MASTER THESIS

Goudappel
MOBILITEIT BEWEEGT ONS

UNIVERSITY OF TWENTE.

Explaining Access Mode Choice for Passengers and Personnel travelling to Schiphol Airport

Master Thesis

Enschede, July 2024

As requested by Schiphol Airport, the text is redacted to make some parts unreadable for publication. The confidential parts are blacked out.

Version
Final report (redacted version)

Author
N.P. (Nick) van Nijen

s2147483

nick.vannijen@outlook.com

Institution
University of Twente,

Department of Transport Engineering and Management (ET-CEM-TEM)

Enschede, the Netherlands

Internal Supervisors
Prof. Dr. Ir. E.C. (Eric) van Berkum

Dr. Ir. O.A.L. (Oskar) Eikenbroek

External Organisation
Goudappel | DAT.mobility

Deventer, the Netherlands

External Supervisors
Dr. Ir. L.J.N. (Luuk) Brederode

Ir. A.V. (Alex) Mouw

Cover picture by Andy Gocher taken on November 24, 2014

PREFACE

Right in front of you is my master thesis with as topic 'Explaining access mode choice for passengers and personnel travelling to Schiphol Airport'. I carried out this thesis at both the 'Mobiliteit & Ruimte' department of Goudappel and DAT.mobility and with this thesis I concluded my master Civil Engineering & Management with a specialisation in Transport & Logistics at the University of Twente. In this master thesis, I estimated the parameters in a discrete choice model to explain access mode choice by the means of explanatory variables, such as travel time and costs. Then, I applied the model to future scenarios to evaluate the effect of measures on the modal share. I hope that this evaluation contributes to a better understanding of the way passengers and personnel travel to Schiphol Airport and how this may change under future conditions.

This thesis gave me the opportunity to gain experience in setting up discrete choice models and to learn about the functioning of Schiphol Airport. The latter emerged explicitly during my visit to Schiphol Airport, for which I am very thankful. I want to thank Jorick Ensing from Schiphol Airport specifically for arranging this visit and being contact person for all my questions related to Schiphol Airport. Also, I want to thank Ronald Wolfers for arranging the main data sources that were utmost necessary for me. Additionally, my thesis phase gave me the opportunity to get to know Goudappel as a company better. Visiting the office in Deventer was besides educational also very enjoyable.

For that and giving me the opportunity to graduate I want to thank Goudappel. Throughout the whole company, people were interested in what you are doing and were always willing to help in sharing data or give advice. More specifically, I want to thank both my external supervisors, Alex Mouw and Luuk Brederode, from Goudappel and DAT.mobility, respectively. Moreover, I want to thank my daily supervisor and UT supervisor from the University of Twente, Oskar Eikenbroek and Eric van Berkum, respectively, for their support. All supervisors provided highly detailed and constructive feedback, which really elevated the level of my work. During the weekly meetings we had great discussions on the matter and these discussions improved my thesis even further.

Enjoy reading my thesis.

Nick van Nijen

Enschede, Monday, 01 July 2024

SUMMARY

Schiphol Airport, the main Dutch Airport, proposes numerous measures in a mobility plan to comply with emission and deposition regulations. Schiphol Airport is interested in the effects of these measures on the access mode choice of passengers and personnel travelling to Schiphol Airport. The aim of this study is to estimate a discrete choice model explanatory for the access mode choice of passengers and personnel to Schiphol Airport and to apply the model in future scenarios to evaluate the effect on the modal share.

For passengers the considered alternatives are public transport; car parking at Schiphol Centrum; car parking at P3; brought by car, parking; brought by car, drop-off; taxi and rental car. All modes demonstrated that an increase in travel time, travel costs and parking costs impedance decreased the likelihood of choosing that mode. Resident travellers prefer the use of car parking, while international travellers prefer the use of taxis and rental cars. Furthermore, trip purpose has a substantial influence on access mode choice. Holiday travellers are less likely to be brought by car, while business travellers are more likely to rent a car or use a taxi. Passengers older than 61 are more likely to use taxis, while the two youngest age groups included in this study (11-20 and 21-30 years old) are less inclined to park their car, possibly due to low car ownership among these groups. In contrast, they prefer the use of public transport. For longer durations of stay, the preferred access mode is being brought by car.

For personnel the included alternatives are car driver; carpooling; bicycle; slow motorised two-wheeler; train and bus. Again, all modes showed a disutility for travel time and costs. For personnel, a statistically significant impedance for the distance to a highway onramp, as well as a(n) (intercity) station was found. Personnel using typical commute hours are inclined to use bicycles, slow motorised two-wheelers and trains. In contrast, aviation workers, often living further away from Schiphol Airport, are less likely to use a bus and carpool. Personnel younger than 39 years old are more likely to use public transport, whereas personnel older than 55 is more likely to use slower modes, such as cycling. It was observed that the frequency of commuting and working from home has little impact on the access mode choice. In contrast, working at Schiphol Centrum is associated with a higher usage of the bus, while driving a car is less likely to occur compared to working outside of Schiphol Centrum.

Besides a good fit, the estimated models were able to provide a modal share closely resembling the observed choice in a 20% validation dataset. That does not only hold for the total modal share but also for more specific segments, based on for example residence and trip purpose. Moreover, the values of time savings, i.e. how much euro people are willing to pay to reduce their travel time by one hour, found in this study were of the same magnitude and following the same proportions as observed in KiM (2023), indicating that the models explain access mode choice to a large extent. Using this knowledge, the models are applied to the passenger and personnel population, obtaining modal shares.

The model is applied to three future scenarios to assess a modal shift. Firstly, when increasing parking fares at P3 by 10%, a decrease of 5.5% in the usage of P3 is expected. Secondly, when projecting the trends for passenger volumes for 2040 distinguishing between residence and trip purpose, a surge in the modal share of taxis (+3.6%), rental cars (+1.3%) and public transport (+1.1%) is expected, while the modal share of car parking (-9.6%) and being brought by car (-2.0%) decreases. However, due to an expected increase in passenger volumes for 2040, the absolute volumes using car parking or being brought by car are still expected to increase. Finally, when projecting personnel growth for 2040, barely any change in modal share is expected.

Both models provide Schiphol Airport with an understanding of variables explaining access mode choice and expectations of mode shifts under future scenarios. The models perform well in capturing proportions in the modal share, but are not accurate enough to estimate absolute traffic volumes per mode on network level. Integrating these models within the Schiphol Travel Demand model of Goudappel is recommended for a better understanding of the effects of a mode shift on the underlying road network around Schiphol Airport.

TABLE OF CONTENTS

1. INTRODUCTION

1.1. PROBLEM CONTEXT

Dutch Airports may only grow in a safe manner, with less hindrance and impact on the environment, as stated in *'Luchtvaartnota 2020-2050'* (Ministry of Infrastructure & Water Management, 2020). This asks for policy and infrastructural measures at and around Schiphol Airport, the main Dutch airport. For example, measures can be taken that affect the way passengers and personnel travel to Schiphol. These measures are outlined in a mobility plan for Schiphol Airport (Goudappel, 2023a), which was specifically developed to comply with emission and deposition regulations in the '*Natuurvergunning*'. Among the proposed measures is the introduction of a paid Kiss & Ride facility and exclusive access to Schiphol Plaza for non-fossil fuelled vehicles (Goudappel, 2023a; Lukassen, 2023). It is anticipated that such measures will induce a modal shift, thereby reducing motorised vehicles volumes on the surrounding road network. Choo et al. (2013) stress the importance of predicting mode choice of air passengers for designing and operating airport facilities and for managing airport access traffic.

Schiphol Airport is interested in the effects of these policy and infrastructural measures on access mode choice and with that the traffic volumes on the airport-surrounding road network. Transport models are typically utilized to assess *a priori* the impact of measures on the distribution of demand over the different transport (sub)systems. These models are used to gain insight into the current state of the transportation system, while allowing for the exploration of future regional and national transportation policies, and thereby facilitate informed decision making and planning (Ortuzar & Willumsen, 2011). Strategic models, such as the widely-adopted four-stage transport model, account for a range of behavioural responses as a result of policy or infrastructural measures, including mode choice. To estimate what the modal share will be under certain measures, it is important to be able to explain mode choice. Discrete choice models are used to quantify the extent to which explanatory variables influence mode choice. Discrete choice models make it possible to disaggregate and personalise the behaviour of individuals and to perceive their preferences according to their characteristics (Aloulou, 2018; Ben-Akiva & Lerman, 1985, Chapter 1; Fosgerau & Bierlaire, 2007; Koppelman & Bhat, 2006, Chapter 1; Schoemakers & Geurs, 2008).

Access mode choice for air passengers is significantly different compared to access mode choice in other contexts (Choo et al., 2013). While normally only travel time and/or costs are considered, for air passengers other factors such as flight destination, parking costs and amount of luggage are also important (Gupta et al., 2008; Jehanfo & Dissanayake, 2009; Jou et al., 2011). As a result, more explanatory variables are needed to explain the mode choice of air passengers. Airport personnel also has different access mode choice preferences, compared to conventional commuters. Due to the 24 hour operation of Schiphol Airport, a wide variety of working hours is in place, underlining the complexity in explaining access mode choice accurately (Choo et al., 2013; Lu et al., 2009; Tsamboulas et al., 2012).

There are multiple transport models in the Netherlands that explicitly model the access transportation to Schiphol Airport. Three of them are the AIRACC module for the Nederlands Regionaal Model (NRM) (Ministry of Infrastructure & Water Management, 2021), AEOLUS (Significance, 2023) and the Schiphol travel demand model (STDM) of Goudappel (2023b). However, these models are not yet suitable for running various future scenarios aiming to change access mode choice. This study focusses on the estimation of a discrete choice model that uses different variables to explain access mode choice of passengers and personnel to Schiphol Airport and applies the estimated model to allow for the evaluation of the effect of future scenarios on the modal share. As a future next step, the estimated model can be integrated with the STDM of Goudappel to allow for the evaluation of the consequences of a modal shift on the traffic volumes on the road network surrounding Schiphol Airport.

1.2. CURRENT TRANSPORTATION MODELS FOR SCHIPHOL AIRPORT

The three above-mentioned models, the NRM, AEOLUS and the STDM, were designed for a different aim or field of application, and thus each model has different advantages and disadvantages with respect to including access mode choice for Schiphol Airport. Both the NRM and the STDM are designed to provide traffic volumes on a road segment level, but respectively on a regional and a local scale. In contrast, AEOLUS is designed to calculate passenger and air freight volumes in order to determine aircraft movements. All models include access modes, but the level of detail in which they are modelled differs between the models.

Key aspects, related to the inclusion of access mode choice, of the three models are summarised in Table 1. For detailed descriptions of the models, I refer to their documentation, Ministry of Infrastructure & Water Management (2021), Significance (2023) and Goudappel (2023a) for the NRM, AEOLUS and the STDM, respectively. The remainder of this section discusses the implications of these key aspects with respect to airport access mode choice. There exist other models (e.g. VENOM (Kieft & Wilgenburg, 2009) and Traffic model Amsterdam (Municipality of Amsterdam, 2019)) that also explicitly model access transportation to Schiphol Airport. However, due to their similarities with the NRM, they are not included in the discussion.

TABLE 1: MODEL COMPARISON

Nr	Aspect	NRM + AIRACC	AEOLUS	STDM
1	Output, the model estimates …	Regional traffic volumes on road segment level	Passenger and air freight volumes to determine aircraft movements	Local traffic volumes on road segment level
2	Inclusion of hinterland	3392 zones (‘NRM moederzones’ in study area)	22 Dutch COROP zones + 5 outside the Netherlands	Hinterland OD’s on PC4 level are clipped to the 16 model’s boundaries
3	Zones at Schiphol	1	1	~150
4	Access modes included	4 (car, public transport, freight, possible to add bicycles)	5 (car (park and k+r), (high speed) train and taxi)	13 (motorised vehicles (e.g. taxi, car (park (passenger and personnel) and k+r), rental), charter/hotel busses and PT busses)
5	Personnel included	Yes	No	Yes
6	Explanatory variables for modelling access mode choice	Travel time	Travel time, distance and costs including parking costs	-
7	Trip purposes	Commute, business, not home restricted business, shopping, education, other	Distinction between business and non-business travellers	Commute, business, shopping, education, other
8	Possibility for running scenarios	Only when timing of the day, travel and fare costs, throughput or demographic characteristics are not included in the scenario	Only when airline fares are excluded from the scenario	The model is only sensitive to changes in passenger numbers, square metres of working area and local network changes

The aim and output of the three models differ substantially from each other. AEOLUS estimates aircraft movements and thus has a totally different aim compared to the other models. As a result, the model structure would need an overhaul to be able to provide traffic volumes. Also, in contrast to the other two models, AEOLUS does not consider through traffic, as this is not of interest when estimating aircraft movements. However, this information is required when estimating traffic volumes on a road segment level.

Goudappel's STDM was developed specifically to gain insight into the traffic implications on the road network around Schiphol as a result of passenger and personnel traffic. Nonetheless, the model output is only sensitive to the number of passengers and the square metres of working area, while in reality traffic volumes and the distribution over different access modes depend on a range of explanatory variables such as travel time. The NRM with the AIRACC module and AEOLUS consider explanatory variables to a larger extent. They include travel time and; travel time, distance and costs, respectively.

In their NRM review focussing on the performance of the AIRACC module, Snelder et al. (2012) mention that only including travel time as an explanatory variable may not resemble the choice made by travellers. Moreover, only including travel time does not allow for running a wide range of (future) scenarios. As no travel and parking costs are included, the distribution over the modes will not change with pricing policies. Also, only free-flow conditions for the car network are considered. As a result, scenarios including an improvement in the flow and/or speed of traffic do not affect the distribution of travellers over the different access modes. Other limitations in the AIRACC module include the negligence of timing of the trip and socio-economic characteristics, while literature indicates that these contribute to airport mode choice.

Peeters and Derudder mention in Hofman (2023) that, as a result of large geographical zones that are used in AEOLUS, trips by competitive modes are described at a relatively low spatial resolution. Also, the NRM with the AIRACC module does not provide the level of spatial detail that is needed to model the volumes on a road segment level. Especially since both models consider only one destination at Schiphol Airport. The STDM includes around 150 zones including different passenger and personnel parking sites, and various working and logistics locations to accurately resemble the traffic volumes, even on relatively minor roads.

The aim and output of AEOLUS are not in line with the interests of Schiphol Airport, regarding the effects of these policy and infrastructural measures on access mode choice and with that the traffic volumes on the airport-surrounding road network. NRM has, besides the spatial resolution, other weak points related to the inclusion of explanatory variables. The spatial resolution is, in contrast, one of the major selling points of the STDM, making it the obvious choice to invest in the inclusion of variables explaining the access mode choice within that model. As a result, this study aims to explain access mode choice of passengers and personnel and apply the estimated model to allow for the evaluation of the effect of future scenarios on the modal share. Later, this can be integrated with the STDM to allow for the evaluation of the consequences of a modal shift on the traffic volumes on the road network surrounding Schiphol Airport.

1.3. Research Design

1.3.1. Research Gap

The previous section showed that the NRM has limitations in both the spatial and the explanatory variable aspect, while AEOLUS fails in the spatial aspect as well as in the output of the model. This illustrates the need for the addition of explanatory variables that explain the access mode choice of passengers and personnel in the STDM of Goudappel.

There is no single answer to how passengers travel to airports across the globe and how this can be explained. This is illustrated by the employment of numerous techniques in studies worldwide, including various discrete choice models, and the inclusion of different explanatory variables. These include studies in Asia (e.g. Choo et al. (2013) and Roh (2013) in South Korea, Jou et al. (2011) in Taiwan), North America (e.g. Hess & Polak (2006) in the San Fransisco Bay Area, Ellis et al. (1974) in the Baltimore – Washington area, Sobieniak et al. (1979) in the Ottawa – Hull area, Gupta et al. (2008) in the New York – New Jersey area) and Europe (e.g. Colovic et al. (2022) for the whole continent, Dissanayake & Jehanfo (2009) in Newcastle upon Tyne).

The above-mentioned studies only included explanatory variables related to the access trip, the individual's characteristics and/or the origin. None of them considered variables related to the flight and its destination, such as trip destination and duration of stay. The latter alone highly influences the parking costs and thus the costs of travelling (Schiphol Airport, n.d.-a), and is therefore likely to be of key importance to include in access mode choice models.

Next to that, current literature seldom includes the access mode choice of personnel (Tsamboulas et al., 2012). Recognizing this gap, Choo et al. (2013) advocate for the integration of personnel considerations in forthcoming research, as personnel has substantially different preferences in access mode choice compared to passengers. Also, compared to the access mode choice of personnel of conventional employers, airport personnel has different preferences (Lu et al., 2009; Tsamboulas et al., 2012). Additionally, Schiphol Airport is planning on implementing measures to stimulate the use of sustainable modes of transportation among their employees and understanding their revealed considerations could help in estimating the effectiveness of these measures. This emphasises the importance of including personnel in access mode choice estimation models.

1.3.2. Research Aim

Access mode choice affects the traffic estimated by the STDM to a large extent. To understand the effect of future scenarios on the access mode choice, a discrete choice model is estimated to explain and estimate access mode choice, based on commonly used explanatory variables like travel time and costs. Also, specific explanatory variables for airport travelling are considered as such flight destination and duration of stay. Taking into account Choo et al.'s (2013) recommendation, the access mode choice preferences of personnel are included as well. Summarizing, the aim of this study is:

"To explain access mode choice of passengers and personnel to Schiphol Airport by estimating a discrete choice model and to apply the model to evaluate the effect of future scenarios on the modal share."

1.3.3. Research Questions

To achieve the aim of the study, four sub-questions are formulated. The first sub-question focusses on potential explanatory variables that play a role in airport access mode choice. Potential variables are identified by executing a literature review. It is important that data is available for these variables for model parameter value estimation. Therefore, the first sub-question is:

Q1 "Which explanatory variables play a role in airport access mode choice to Schiphol Airport according to literature and for which of these variables is data available for discrete choice model estimation?"

With the potential explanatory variables known, a (tree of) discrete choice model(s) is/are estimated using passenger and personnel questionnaire data describing the chosen alternatives and their attributes amended with geospatial data describing the availability and attributes of non-chosen alternatives. Discrete choice models are able to model choices that are made by passengers and personnel. The type of discrete choice model that is used is determined based on a literature review. Then, the model is validated for its explanatory power. Summarizing, the second sub-question is:

Q2 "How (well) explain the estimated parameters of the discrete choice model access mode choice and what is their coherence and importance?"

By understanding how and to what extent explanatory variables influence access mode choice, the estimated model is applied to the full population of passengers and personnel, resulting in a corresponding estimated modal share. Therefore, the third sub-question is:

Q3 "What is the model share when applying the estimated access mode choice model on the whole population of passengers and personnel in a base scenario?"

Finally, the model is used to estimate the modal share under future conditions. These conditions are shaped by potential policy and infrastructural measures, as well as trends in passenger and personnel volumes and composition. For this, three future scenarios are selected, namely a 10% parking fare increase at P3, projecting passenger purpose and residence composition for 2040 and projecting personnel growth for 2040. Therefore, the fourth and last sub-question is:

Q4 "How does the modal share change in future scenarios, compared to the base scenario?"

1.4. RESEARCH SCOPE

The remainder of this section focusses on the choices that should be modelled in airport access mode choice. Thereafter, the exclusion of access modes for cargo is justified.

1.4.1. BEHAVIOURAL CHOICES

There are many choices to be made when travelling, so also when flying. These behavioural choices are whether or not to travel, destination choice, airport choice, airline choice, main leg mode choice, and access mode choice. Behavioural choices are defined as the description of response allocation patterns when making a selection across several choice alternatives (van Wingerden & Kalenscher, 2022). Preferably, as many behavioural choices are included are included in the decision-making process of an individual, because behavioural choices are often inter-dependent (Hess & Polak, 2006; Ishii et al., 2009; Pels et al., 2001; Zijlstra, 2020). For example, when choosing a certain flight destination, you are bounded to the airports and the timeslots of these airports that fly to this specific destination. However, this study does not include all behavioural choices, but scopes specifically towards access mode choice.

Although all choices are illustrated to be of importance according to literature, not all have to be included in the STDM of Goudappel. The AEOLUS model already accounts for numerous of the aforementioned behavioural choices. The model includes the utility of making a trip and also compares the utility of different modes, including car, (high speed) rail and airplane. When the disutility of travelling is too high, the trip will not be made. In the AEOLUS model a choice is made between 29 destination zones around the globe. Moreover, the AEOLUS model accounts for choices between fourteen airports in the Netherlands and outside and between five alliances within airlines, of which one is low-cost carriers. Airlines within the same alliance often have corresponding characteristics and are therefore considered together in the AEOLUS model (Significance, 2023). The AEOLUS model also considers access mode choice to estimate passenger volumes, however only on a limited level of detail. As mentioned in Section 1.3.1, the AEOLUS model remains unsuitable for this study, due to this. Nevertheless, the outcomes, passenger and cargo volumes, can be used in the STDM when running a future scenario. As a result, access mode choice remains the sole considered behavioural choice included in this study.

1.4.2. EXCLUSION OF CARGO

This study focusses on modelling access mode choice of passengers and personnel. Even though cargo transport constitutes of 1.38 million tonnes of cargo and 15,969 full freighter aircraft movements in 2023 from Schiphol Airport (Schiphol Group, 2023), it is deemed reasonable to exclude cargo transport from this study. The modal share of landside transport of cargo is expected to be affected only to a limited extent by policy and infrastructural measures proposed in Goudappel (2023a). Next to that, AEOLUS already considers and calculates cargo volumes. It would thus not be useful to again include cargo transport in access mode estimation. Even though cargo volumes are definitely affected by external factors such as airport charges, night flying restrictions, presence of freight forwarders and disruption such as the Covid-19 pandemic (Gardiner et al., 2005; Karunathilake & Fernando, 2023).

1.5. REPORT OUTLINE

This section introduced the research by explaining the problem context and the subsequent research gap, aim, questions and scope. The next section discusses literature on the use of discrete choice models and literature on airport access mode choice for passengers and personnel. The latter focusses specifically on the alternatives in and the variables explanatory for airport access mode choice. Then, background on the study area and the datasets for passengers and personnel are provided in Section 3. Section 4 introduces the methodology in general and dives deeper into the details to answer all research questions. The results are provided in two sections. The first (Section 5) discusses the results of the estimation of the models and their validity and the second section (Section 6) discusses the results of applying the models on three future scenarios. In Section 7, the effects of limitations in the data and used methods are formulated, as well as generalisations on the study area are described. This study concludes with the conclusions per research question, an overarching conclusion and recommendations in Section 8.

2. LITERATURE RESEARCH: DISCRETE CHOICE MODELS ON ACCESS MODE CHOICE OF AIRPORTS

2.1. MODEL FORMS

Discrete choice models describe decision makers' choices among alternatives (Train, 2009, Chapter 1). This approach is often referred to as the disaggregated approach, since it models individual choice responses (Koppelman & Bhat, 2006, Chapter 1). An advantage of this approach over the aggregated approach is that changes in behaviour as a result of changes in individual characteristics and the attributes of alternatives are better reflected (Aloulou, 2018; Ben-Akiva & Lerman, 1985, Chapter 1; Fosgerau & Bierlaire, 2007; Koppelman & Bhat, 2006, Chapter 1; Schoemakers & Geurs, 2008). Next to that, the obtained parameters are unbiased, if properly specified, and the disaggregated approach allows to capture heterogeneity in the population (Fosgerau & Bierlaire, 2007; Koppelman & Bhat, 2006, Chapter 1). Acknowledging these advantages over aggregated transportation models, discrete choice models are increasingly used in transportation models from the 1980's onwards (Schoemakers & Geurs, 2008).

The random utility framework is often assumed in discrete choice modelling. This framework, established by McFadden (1974), assumes that individuals act as maximising their utility, when choosing between a discrete set of alternatives. In an airport access mode choice context, this assumption is often made (Dissanayake & Jehanfo, 2009). This utility U_{in} is estimated using a utility function (Equation 1) and depends on a vector of observable explanatory variables $\boldsymbol{x}_{in}$ with corresponding model parameters per alternative $\boldsymbol{\beta}_n$, called the systematic utility, and the random error term ε_{in}. The latter is included, since the modeller always has incomplete and imprecise information (Koppelman & Bhat, 2006, Chapter 3).

$$U_{in} = \boldsymbol{\beta}_n \boldsymbol{x}_{in} + \varepsilon_{in} \quad \text{Eq. 1}$$

The multinomial logit (MNL) model and the nested logit (NL) model, both generalised extreme value models, are most often employed in literature. Choo et al. (2013) mention that it is unclear whether the use of the MNL or NL model is more appropriate. Besides, the mixed multinomial (MMNL) model is an interesting option, as it allows for random taste variation across individuals. Sections 2.2 and 2.3 introduce two other aspects of the utility function in a discrete choice model, namely the alternatives in the choice set and the explanatory variables, respectively.

2.1.1. MULTINOMIAL LOGIT MODEL

Multinomial logit models are used when more than two alternatives are observed and model the proportion between the utilities of the different alternatives (Liu, 2016). These utilities are constructed using various observed explanatory variables and an error term (Dissanayake & Jehanfo, 2009; Koppelman & Bhat, 2006, Chapter 3). The mathematical formulation to calculate the probability of choosing alternative n by individual i is expressed in Equation 2 as proposed in Train (2009, Chapter 3).

$$P_{in} = \frac{e^{V_{in}}}{\sum_{j=1}^{n} e^{V_{jn}}} \quad \text{Eq. 2}$$

This model is the most widely used discrete choice model, particularly, due to its simplistic probabilistic choice function, the ease in the interpretation of the results and the ease in understanding the derivation of the final probabilistic choice function. Nonetheless, MNL models are not suitable when there is a natural order in the alternatives. Moreover, MNL models assume independence between the outcome alternatives. MNL models are often used in relatively older studies, due to their ease and many studies substantiate on their usefulness (Roh, 2013).

Dissanayake & Jehanfo (2009) employed a MNL model in their study on ground access modes of air passengers, specifically focussing on behavioural interpretations of passengers' mode choice. Their considered alternatives were car parking, car Kiss & Ride, metro, taxi and bus. Their explanatory variables were among others travel time, luggage count and size of the access group. They used segmented MNL models to isolate specific explanatory variables. They used this procedure to evaluate the difference between leisure and business travellers, between domestic and international travellers and between incomes over 20,000 £ and below. Roh et al. (2013) also employed multiple MNL models to isolate the effect of trip distance and purpose.

2.1.2. Nested Logit Model

Nested logit models are used when the problem involves decisions across several dimensions of choices (Lo et al., 2004). In that case the set of alternatives can be partitioned into subsets, called nests. Regarded as a more sophisticated alternative to MNL models, NL models conceptualize decision-making through the construction of a decision tree, assuming individuals make sequential decisions. Between alternatives in the same nest, the probability is independent of the other alternatives, while dependency may exist between the alternatives in different nests (Train, 2009, Chapter 4). The mathematical formulation to calculate the probability of choosing alternative n by individual i is expressed in Equation 3 following Train (2009, Chapter 4). In this equation, the nests are represented by B and λ is a parameter representing the degree of independence in unobserved utility in a specific nest (Train, 2009, Chapter 4).

$$P_{in} = \frac{e^{V_{in}/\lambda_k}\left(\sum_{j\in B_k} e^{V_{im}/\lambda_k}\right)^{\lambda_k - 1}}{\sum_{l=1}^{K}\left(\sum_{j\in B_l} e^{V_{im}/\lambda_l}\right)^{\lambda_l - 1}} \qquad \text{Eq. 3}$$

Gupta et al. (2008) employed a NL model in the New York City metropolitan region when evaluating airport and access mode choice but saw a statistically preference for a MNL model. The decision tree considered in Gupta et al. (2008) is presented in Figure 1, so first the airport choice and then the access mode choice is made. Also, Hess & Polak (2006) used a three level NL model, where airport, airline and access mode choice were of interest. These studies show that a NL model is only useful when decisions are made on different levels.

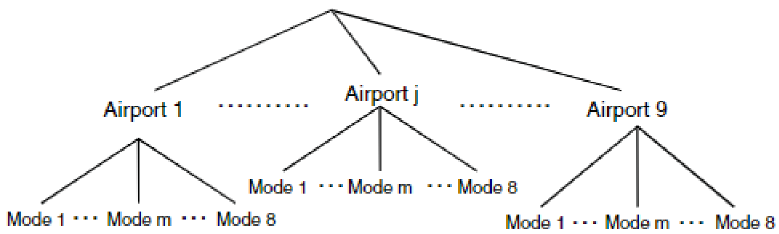


FIGURE 1: STRUCTURE OF JOINT AIRPORT AND MODE CHOICE NESTED LOGIT MODEL (GUPTA ET AL., 2008)

2.1.3. Mixed Multinomial Logit Model

Hess & Polak (2005) identified significant advantages of using a mixed multinomial logit (MMNL) model, over a MNL model, as it allows for random taste variation across decision makers. This advantage was also identified by Jou et al. (2011). Instead of estimating the model parameters β, the MMNL model estimates the parameters of a predefined probability distribution function. The mathematical formulation to calculate the probability of choosing alternative n by individual i is expressed in Equation 4 as proposed in Train (2009, Chapter 6). In this equation, $f(\beta)$ represents a chosen density function and $V(\beta)$ is the observed portion of the utility depending on parameters β. Often employed density functions are lognormal, uniform, triangular or gamma (Train, 2009, Chapter 6).

$$P_{in} = \int \frac{e^{V_{in}(\beta)}}{\sum_{j=1}^{n} e^{V_{jn}(\beta)}} f(\beta) d\beta \qquad \text{Eq. 4}$$

Additionally, the model avoids the irrelevant alternatives assumption, which dictates that the dependency between alternatives is the same for all alternatives. However, it is pertinent to acknowledge drawbacks associated with MMNL models, such as their sensitivity to the selection of probability distribution functions for random taste parameters and challenges in computation as an MMNL model does not have a closed form (Hess et al., 2005; Hess & Polak, 2005; McFadden & Train, 2000).

Jou et al. (2011) employed an MMNL model in their study to Taiwanese Tuoyouan International Airport and investigated the current airport access mode choice and what effect a future mass rapid transit line could have on this mode choice. The use of an MMNL model showed great potential as the researchers obtained an adjusted R^2 value of 0.83. Gunay & Gokasar (2021) also used the MMNL model in their study to access mode choice for the Ataturk International Airport in Istanbul. In fact they compared the performance of the MNL and MMNL model and found the latter to be superior to the first with respect to the adjusted R^2 value. Both used normally distributed density functions.

2.2. ALTERNATIVES

In a discrete choice model, there is always a discrete choice set from which the alternatives are drawn (Train, 2009, Chapter 2). There exists a wide range of alternatives for airport access mode choice. However, the options vary across different studies and different geographical locations as presented in Table 2. Among the considered studies, all included different private motorised vehicle options, like car parking and Kiss & Ride. Only Ellis et al. (1974) and Sobieniak et al. (1979) did not include forms of public transport in their studies, as they were not available at that time in their study areas in the United States. Besides studies focussing on access mode choice of passengers, two other studies focussing on airport personnel are included in the table.

2.3. EXPLANATORY VARIABLES

Within a discrete choice model, the systematic utility is described by the vector of explanatory variables and corresponding model parameters per alternative. This section introduces potential variables explaining access mode choice when travelling to airports according to literature. The estimated model parameters play an important role in explaining which mode air passengers and personnel choose when traveling to Schiphol Airport. Additionally, the parameters of the model help in estimating changes in the mode choice when a variable changes.

As Choo et al. (2013) indicate explanatory variables are different in airport access compared to other transportation models. This does not only hold for passengers, but also for airport personnel. There are similar variables as in other transportation contexts, like travel time and/or costs. However, in the airport context other variables, like the amount of luggage and group size, may play a role in the access mode choice as well. The explanatory variables found in literature are summarised in Table 3. It should be noted that the included studies all use one of the discrete choice models described in Section 2.1, except from Choo et al. (2013). They used logistic regression when comparing two alternative mode options. Moreover, all studies used revealed preference questionnaires. Tsamboulas et al. (2012), Alkaabi (2016) and Jou et al. (2011) used a combination of both stated and revealed preference data and Jou et al. (2011) used it specifically to identify potential effects of a new mass rapid transit on the access mode choice. The remainder of this section introduces explanatory variables found in other studies in more detail. Potential variables are classified in variables related to the trip, the origin, the individual traveller and variables specific for airport personnel.

TABLE 2: SUMMARISING TABLE OF THE INCLUDED ACCESS MODES

	Passengers										Personnel	
Reference	(Choo et al., 2013)	(Colovic et al., 2022)	(Dissanayake & Jehanfo, 2009)	(Ellis et al., 1974)	(Gunay & Gokasar, 2021)	(Gupta et al., 2008)	(Hess & Polak, 2006)	(Jou et al., 2011)	(Roh, 2013)	(Sobieniak et al., 1979)	(Alkaabi, 2016)	(Tsamboulas et al., 2012)
Location	Seoul and Deagu, South Korea	Europe	Newcastle uponTyme, UK	Baltimore – Washington, USA	Istanbul, Turkey	New York – New Jersey, USA	San Fransisco Bay Area, USA	Taipei, Taiwan	Seoul, South Korea	Ottawa – Hull, Canada	Dubai, United Arab Emirates	Athens, Greece
Private motorised vehicles	■	■	■	■	■	■	■	■	■	■	■	■
Private car	■	■	■	■	■	■	■	■	■	■	■	■
- Kiss & Ride		■	■		■	■		■		■		
- Parking		■	■		■	■		■		■	■	
Rental car				■		■		■				
Taxi	■	■	■	■	■	■	■		■	■	■	
Limousine	■			■		■	■		■	■		
Public Transport	■	■	■		■	■	■	■	■		■	■
Rail		■				■		■				■
Bus	■	■	■			■	■	■	■			■
- Charter bus						■	■					
- Local bus						■		■				
Metro	■	■	■					■	■			■

TABLE 3: SUMMARISING TABLE OF EXPLANATORY VARIABLES

	Passengers										Personnel	
Reference	(Choo et al., 2013)	(Colovic et al., 2022)	(Dissanayake & Jehanfo, 2009)	(Ellis et al., 1974)	(Gunay & Gokasar, 2021)	(Gupta et al., 2008)	(Hess & Polak, 2006)	(Jou et al., 2011)	(Roh, 2013)	(Sobieniak et al., 1979)	(Alkaabi, 2016)	(Tsamboulas et al., 2012)
Location	Seoul and Deagu, South Korea	Europe	Newcastle uponTyme, UK	Baltimore – Washington, USA	Istanbul, Turkey	New York – New Jersey, USA	San Fransisco Bay Area, USA	Taipei, Taiwan	Seoul, South Korea	Ottawa – Hull, Canada	Dubai, United Arab Emirates	Athens, Greece
Trip Variables												
Travel Time	X	X	X	X	X	X	X	X	X	X	X	X
- Out-of-Vehicle Time							X	X		X		
○ Waiting Time							X			X		
○ Walking Time							X			X		
- In-Vehicle Time							X	X		X		
Travel Cost	X		X	X	X	X	X	X			X	X
- Parking Costs						X		X			X	
Trip purpose	X			X		X	X		X	X		
Origin Variables												
Proximity to Public Transport					X							
Individual Traveller Variables												
Cars per Household			X		X			X			X	
Access Group Size			X			X						
Amount of Luggage			X					X				
Gender	X					X			X	X	X	
Age	X					X			X			
Residence					X	X	X					
Income	X	X				X	X	X		X	X	X
Employment					X							
Personnel Specific Variables												
Type of Work											X	
Nationality											X	

2.3.1. VARIABLES RELATED TO THE TRIP

2.3.1.1. TRAVEL TIME

Passengers show a high sensitivity to travel time when traveling to an airport (Dissanayake & Jehanfo, 2009; Ellis et al., 1974; Gunay & Gokasar, 2021; Gupta et al., 2008; Hess & Polak, 2006). Roh (2013) found in a study at Kimpo Airport, South Korea, that their value of time savings was between 1.6 and 2.4 times as large compared to travellers in another context besides airports and that travel time becomes even more important when the distance to an airport increases. Jou et al. (2011) made a distinction between in-vehicle and out-of-vehicle travel time and saw both having a significant influence. They identified the in-vehicle time as the time spent in a certain mode of transport and the out-of-vehicle time is the time spent between the chosen mode of transport and the terminal building of the airport. An example of this is the time spent walking and/or being transported from the parking site to the terminal building. Hess & Polak (2006) and Sobieniak et al. (1979) made an even more detailed distinction by including walking time, waiting time and in-vehicle time and saw that all were statistically significant. Sobieniak et al. (1979) studied access mode choice to all kind of international terminals, including bus and rail terminals. As a result, their analysis on air terminals included relatively little explanatory variables. This might explain why they obtained a relatively low R^2 value and an accuracy of at most 63%. Colovic et al. (2022) found in a study across multiple countries throughout Europe that travellers who prefer private vehicles are more sensitive to travel time and waiting time, while contrary public transport travellers are more sensitive to travel costs and reliability. Nonetheless, it should be noted that in their study, they only reached an average accuracy of 40.3%.

2.3.1.2. TRAVEL COST

One of the first studies in airport access mode choice by Ellis et al. (1974) for the Baltimore-Washington Airport, USA, already identified the importance of travel costs for passengers. This claim is supported by many later studies (Choo et al., 2013; Dissanayake & Jehanfo, 2009; Gunay & Gokasar, 2021; Gupta et al., 2008; Hess & Polak, 2006; Jou et al., 2011). Some of these studies identified specifically parking costs as an explanatory variable (Gupta et al., 2008; Jou et al., 2011).

2.3.1.3. TRIP PURPOSE

Especially, trip purpose is found to be of importance in access mode choice (Ellis et al., 1974; Gupta et al., 2008; Sobieniak et al., 1979). Hess & Polak (2006) found the benefit of using specific models for different journey purposes in their study considering airport, airline and access mode choice to airports in the San Fransisco Bay Area. This means that for the three different purposes included (business, holiday or traveling with friend/family) a different model was estimated and for the different estimates for the explanatory variables were found. Moreover, they estimated separate models for different nesting structures following their NL approach. Following an adjusted R^2 value of over 0.40 for most models, their models were relatively accurate in explaining the variability in the dependent variable. Choo et al. (2013) compared the car with public transport using logistic regression in a case study in South Korea. They made a distinction between business and non-business travellers and found that business travellers show a tendency to choose a car as access mode. However, Roh (2013) found that business travellers between 30 and 40 show the opposite behaviour, possibly due to costly parking fees. Gupta et al. (2008) made the same distinction as Roh (2013) and found statistically significant differences. However, it should be noted that following the log likelihood, the model for business travellers outperformed the non-business model substantially.

2.3.2. VARIABLES RELATED TO THE ORIGIN

Variables related to the origin could play a role in explaining access mode choice in an airport context. Gunay & Gokasar (2021) identified the positive effect of originating from an area in close proximity (1/2 mile) to a (semi-)rapid transit stop on the use of public transport.

2.3.3. VARIABLES RELATED TO THE INDIVIDUAL TRAVELLER

Variables related to the individual traveller that are of significance are the number of cars per household, the amount of luggage being taken to the airport and access group size according to Dissanayake & Jehanfo (2009) in their study in Newcastle upon Tyne, UK. Nonetheless, it should be noted that their MNL model was only able to indicate 18.1% of the variation in the dependent variable by the variance in the explanatory variables as indicated by their R^2 value. The significance of the number of cars per household was also observed in Jou et al. (2011) where they studied Taoyuan International Airport, Taiwan and in Gunay & Gokasar (2021) where they studied Ataturk International Airport, Turkey. The first study included more explanatory variables than Dissanayake & Jehanfo (2009), which resulted in an adjusted R^2 value of 0.83. Therefore, their model is better in estimating the variability in the dependent variable through their explanatory variables.

Furthermore, the size of the access group was observed as being significant in Gupta et al. (2008) in a study in the New York – New Jersey metropolitan area. They also identified the importance of gender and age. The latter was also observed in Choo et al. (2013) and Roh (2013). Choo et al. (2013) stated that elderly are more likely to choose a car, since they feel uncomfortable in accessing and taking a subway, while Gupta et al. (2008) saw that younger people, below 35 years old, prefer transit, taxis and shared rides. Moreover, Hess & Polak (2006) employed different models for resident and international travellers and saw different variables play a role in explaining their access mode choice. Gupta et al. (2008) included a dummy for resident travellers and saw that residents are more likely to park their car, whereas they are less likely to rent a car.

The amount of luggage was implicitly included in Dissanayake & Jehanfo (2009) and in Jou et al. (2011), since they included information about how problematic the baggage handling would be and the convenience of storing and retrieving luggage, respectively.

Additionally, household income level is contributing to a choice in access mode (Choo et al., 2013; Colovic et al., 2022; Gupta et al., 2008; Hess & Polak, 2006; Jou et al., 2011). Choo et al. (2013) found that air travellers with a relatively high income prefer the use of a private car over public transport. Also, Colovic et al. (2022) identified that the probability of choosing a taxi over a combination of modes is positively influenced by high household incomes. Also, Gupta et al. (2008) saw that lower-income households have a larger disutility associated with taxis, rental cars or parked cars. Related to income, Gunay & Gokasar (2021) identified the effect of employment. Employed passengers are less likely to use Kiss & Ride facilities.

2.3.4. VARIABLES FOR AIRPORT PERSONNEL

Just as for passengers, travel time and costs are highly important explanatory variables for personnel (Alkaabi, 2016; Tsamboulas et al., 2012). Besides that, personnel with a net income of more than € 1,000 per month are more likely to use private cars or the metro as found in Tsamboulas et al. (2012) where they studied airport personnel in Athens, Greece. In Dubai, United Arab Emirates, Alkaabi (2016) found that higher incomes are associated with a higher car usage. The latter study also identified that full-time workers are more likely to use cars and public transport, compared to part-time workers. They also identified the statistically significant influence of the nationality of personnel and having a parking permit, whereas variables as educational level, type of work, gender, age and the number of owned cars were not found statistically significant. Tsamboulas et al. (2012) emphasized the impact of job type on access mode choice, yet surprisingly did not include any related variables.

3. STUDY AREA & DATA

In this section, the study area, as well as the two questionnaire datasets used for this research are introduced. One for passengers (Section 3.2.1) and one for personnel (Section 3.2.2)

3.1. SCHIPHOL AIRPORT

This study focusses on Schiphol Airport, situated in the Haarlemmermeerpolder, South of Amsterdam. Schiphol Airport handled 61.9 million passengers in 2023 and is ranked the 4th biggest airport in Europe when it comes to passenger transport (Schiphol Group, 2023). Of all passengers, 63.7% have an origin or destination in the hinterland of Schiphol Airport. Moreover, Schiphol Airport is estimated to be directly and indirectly responsible for 4.5% of the gross domestic product of the Netherlands, also stressing its importance as an economic driver in the region and for the nation (Schiphol Group, 2015). At the Schiphol areal work 68,000 employees and another 45,000 work at their suppliers (NOS, 2020). The Schiphol areal is defined by the area covered by nine working locations defined by Schiphol Airport presented in Figure 2. For passengers solely Schiphol Centrum is of interest, since the terminal building is situated here.

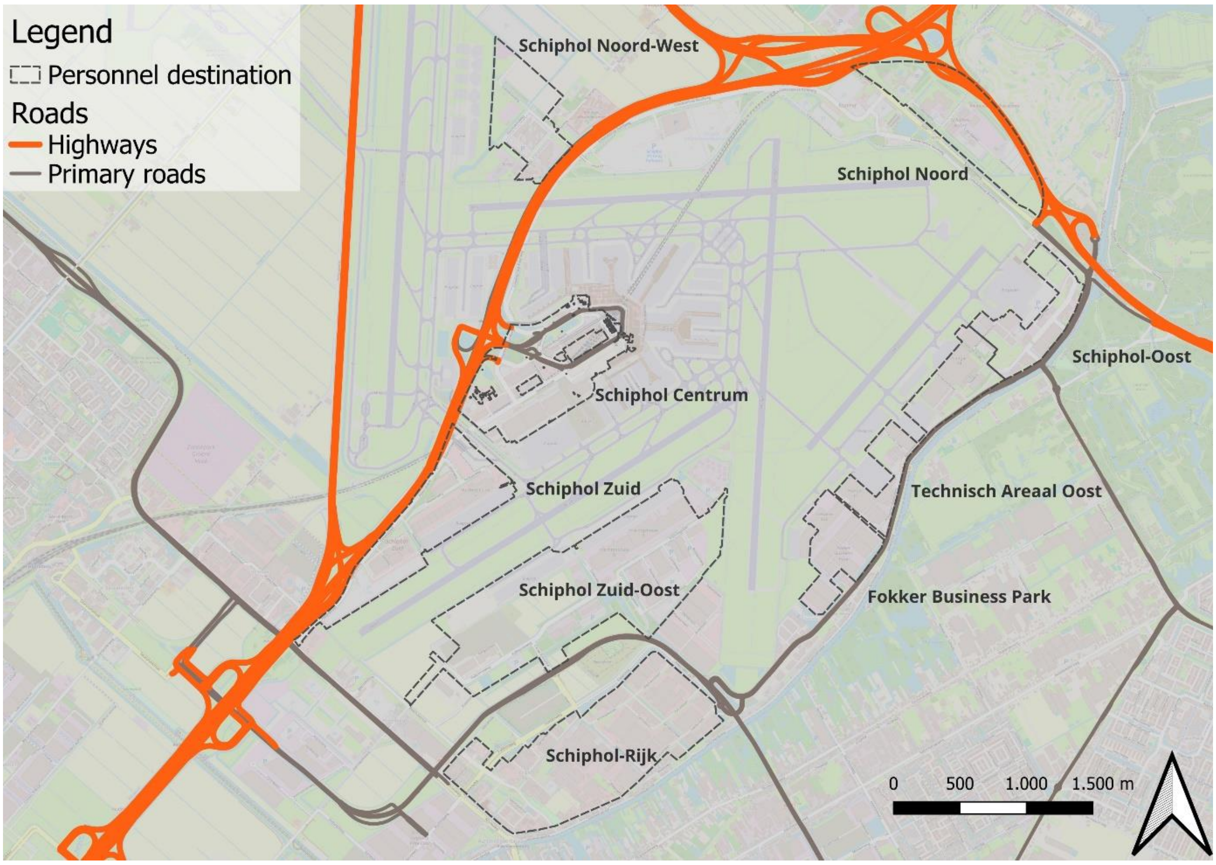


FIGURE 2: SPATIAL DISTRIBUTION OF PERSONNEL ZONES

De Neufville & Odoni (2013) estimated that each employee makes around 500 single trips to the airport annually, while passengers make, on average, only two round trips. Ameen & Kamga (2013) saw a ratio of 1 to 0.48 between the total annual passenger trips and personnel trips at John F. Kennedy Airport, New York. This indicates that trips made by personnel indeed have a substantial influence on the transportation system.

The remainder of this section provides more details on the infrastructure around Schiphol Airport for some modes in general, namely car and public transport.

3.1.1. ACCESS MODE: CAR

Schiphol is well-connected to the Dutch road infrastructure. Schiphol Airport is mostly accessed by motorised vehicles using highway A4 towards The Hague and Rotterdam and the A4 heading towards Amsterdam. These highways are connected with multiple other highways in the close proximity to Schiphol Airport, such as the A1, A2, A5, the A9 and the A10 as visualised in Figure 3.

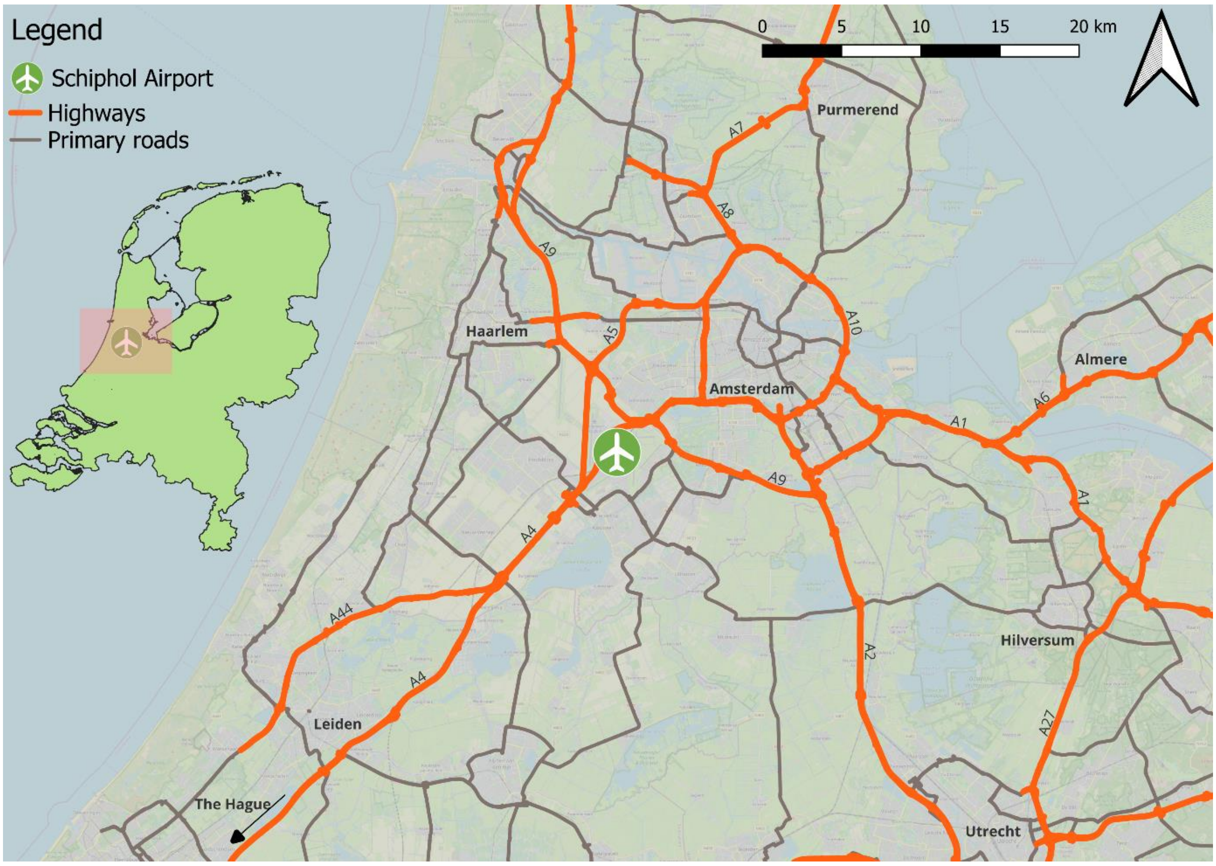


FIGURE 3: REGIONAL CAR NETWORK AROUND SCHIPHOL AIRPORT

There are a total 14 parking sites at Schiphol Airport. The spatial distribution of these parking sites is presented in Figure 4. In total, there are 37,125 car parking spaces in 2023, from which 24,875 are for passengers and visitors and 12,250 are for employees (Schiphol Group, 2023).

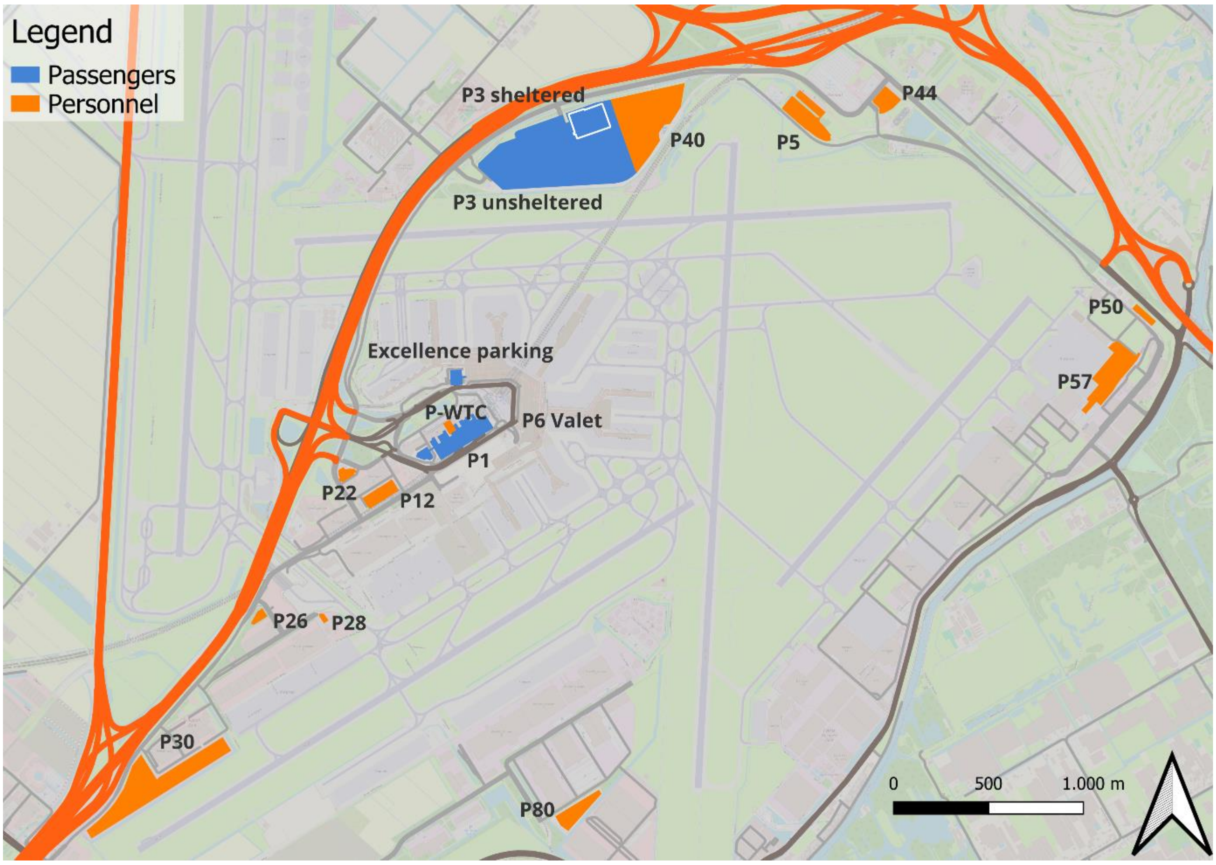


FIGURE 4: PARKING SITE DISTRIBUTION AROUND SCHIPHOL AIRPORT

For passengers, there are 6 parking sites available. Their parking fees and the out-of-vehicle time (i.e. how far they are from the main terminal building in minutes) are presented in Table 4. The fees are from 2024-01-19 and are for not reserving a parking spot. The fee for reserving a parking spot depends on how far in advance the parking spot is reserved, the time of the year and the availability, but are always cheaper than non-reserved fares (Schiphol Airport, n.d.-b). Due to their flexibility and variability, reserved parking fares are not included in the table. It was observed that the fare ratio between the different parking sites is similar for reserving as it is for not reserving. Note that P1 pick-up and drop-off also charges fees per 20 minutes on the first day of parking, namely € 2.30 (Schiphol Airport, n.d.-a).

TABLE 4: PASSENGERS PARKING FEES

Name	Costs [per specific day] [€/day]	Out-of-vehicle time (using mode) [min]	Notes
P1 Pick-up and Drop-off	51 [1st-2nd day], 100 [3rd day or more]	4 (walk)	
P3 Long Term Sheltered	51 [1st day], 44 [2nd day], 12 [3rd day or more]	5 (shuttle bus)	
P3 Long Term Unsheltered	51 [1st day], 34 [2nd day], 12 [3rd day or more]	5 (shuttle bus)	
Privium 1	51 [1st-3rd day], 100 [4th day or more]	2 (walk)	Only for Privium members
Privium 3	51 [1st day], 44 [2nd day], 12 [3rd day or more]	5 (shuttle bus)	Only for Privium members
Privium Excellence	57.75	0	Only for Privium members

For personnel there are 12 parking sites available, which are managed by Schiphol itself (see Figure 4). These parking sites have monthly fees, which are higher for sites close to Schiphol Centrum compared to parking sites further away. Schiphol Airport wishes to have these fees paid by the employer instead of charging them back to the employees, as agreed in a social agreement (Zinger, 2024). However, this does not represent the current situation fully as their exists companies around the Schiphol areal for the consequences of this social agreement are not (yet) implemented. Despite this, it is considered reasonable to exclude personnel parking costs from this study.

3.1.2. ACCESS MODE: PUBLIC TRANSPORT

Schiphol Airport is accessible by public transport via international, national and regional train service. In total 12 lines arrive at Schiphol at least twice per hour. Moreover, the Thalys to Paris, via Antwerp and Brussels and the High Speed Line (HSL) serve Schiphol (NS, 2023). Additionally, Schiphol Airport is served by 24 direct bus lines and multiple other (chartered) bus connections provided by, for example, Flixbus. The direct public transport connections of Schiphol Airport are presented in Figure 5.

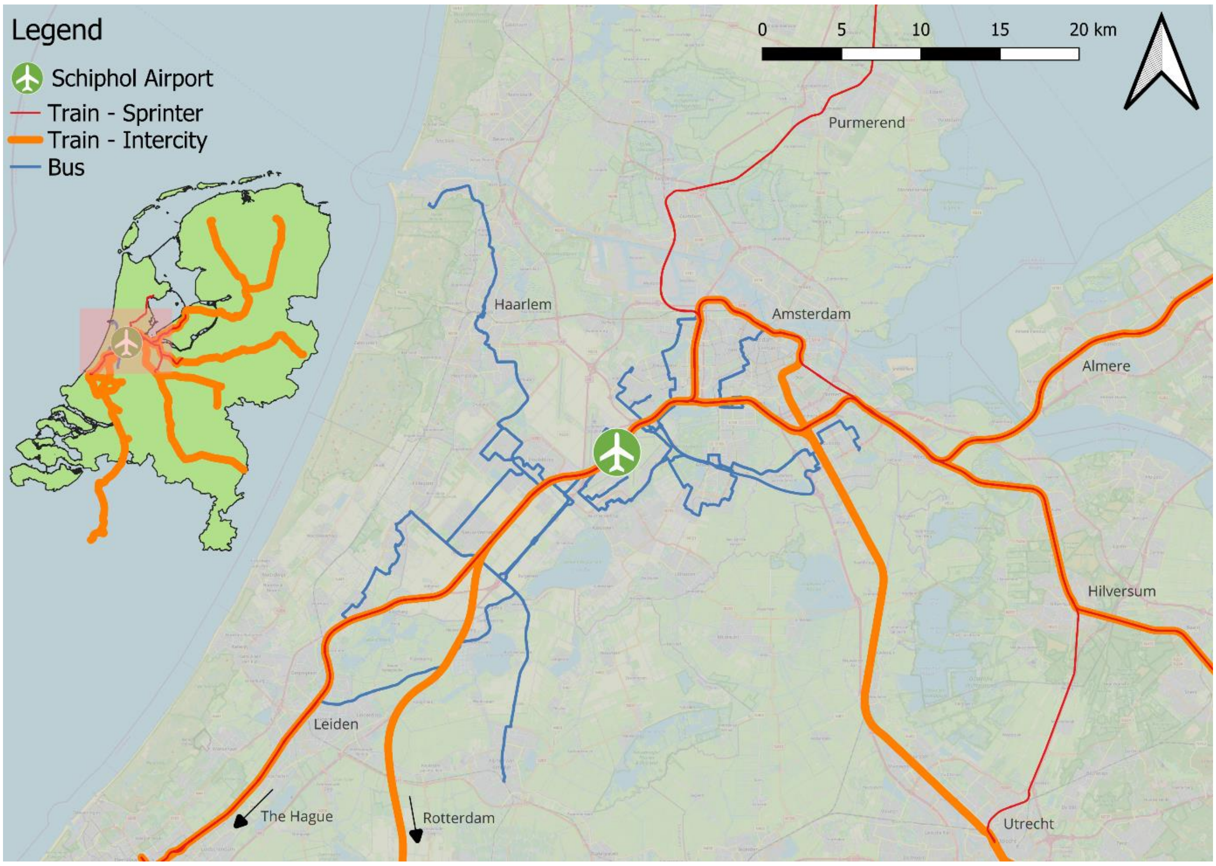


FIGURE 5: DIRECT PUBLIC TRANSPORT CONNECTIONS TO SCHIPHOL AIRPORT

3.2. QUESTIONNAIRE DATA

Schiphol Airport provided the data of two questionnaires. One was conducted among passengers and one among personnel.

3.2.1. PASSENGER DATA

The passenger data is obtained using a revealed preference questionnaire conducted at the airport, called the Routes and Profile Monitor (RPM). The interviewee is chosen randomly among departing passengers in the terminal building at the gate of the departing flight. The questionnaire is conducted daily, including weekends, during three time frames: morning, afternoon, and evening. The interviewee fills out the questionnaire on an iPad under the supervision of an interviewer. Employing a personal questionnaire has the advantage of having a higher consistency and reliability compared to a mailed questionnaire (Abubakar et al., 2020; Zusman, 1973). However, data inconsistencies are still expected as the interviewer does not or cannot verify the answers. This questionnaire is only conducted among departing passengers. When interviewing passengers in the terminal building before departure, passengers can report on the trip they just made to the airport. If this would have been done for arriving passengers, they should be asked at their destination in the hinterland of Schiphol Airport. This is logistically impossible when employing a personal questionnaire. Also, previous studies often employed data on departing passengers only, due to data-unavailability (Hess & Polak, 2006). Only including data on departing passengers is deemed reasonable, as passengers often use the same mode of transport back and forth. This is especially the case for resident passengers. Nevertheless, for arriving tourists this might be of less application (Ameen & Kamga, 2013). For example, when arriving by private car, that car is also used to return to the origin. Due to this inter-dependency, return trips influence the access mode choice. For example, a respondent's departing flight is during the day, while his return flight is during the night. In that case, public transport is not an option as egress mode for the return flight, affecting the access mode choice. Nonetheless, no information is available for arriving passengers, hence the effect of the return flight is excluded.

For this study, the data from quarter 1 of 2023 to quarter 4 of 2023 is used, resulting in 54,588 responses. This time frame was deemed sufficient by Schiphol Airport, due to representative modal share resembling pre-Covid-19 times (Schiphol Group, 2024). The variables that are included in this dataset are presented in Table 5. For the access mode 'car parking' it is known on which parking site they parked their car and for 'brought by car' it is known if they did this via the drop-off facilities or by parking at P1 parking site, specifically designed for this purpose. Finally, it is known whether or not a parking spot was reserved or not.

TABLE 5: VARIABLES INCLUDED IN THE RPM

Variable	Type of variable/alternatives
Origin	Categorical; municipal code following CBS for Dutch origins, country for all passengers for origins in other countries
Place of residence	Categorical; PC4 code following CBS when available for Dutch residents
Time of flight	Categorical; divided in classes of one hour
Flight destination	Categorical; Schengen, non-Schengen
Purpose	Categorical; holiday, visiting relatives, business, conference, other
Domestic traveller	Binary; whether or not a traveller lived in the Netherlands for the past 12 months
Trip duration	Categorical; 1 day, 2 days, 3 days, 4-7 days, 8-13 days, 14-20 days and 20+ days
Age	Categorical; classes of 10 years till 80+
Gender	Categorical; male, female, not willing to say
Access mode	Categorical; car parking, brought by car, charted bus, hotel bus, regular bus, rental car, taxi, train, walking and other

The RPM responses corresponds with 0.28% of the total departing passengers at Schiphol Airport (Schiphol Group, 2023). 96.2% of the interviewed respondents travel from an origin in the Netherlands. Of the remainder, 1.9%, 1.4% and 0.4% travel from Belgium, Germany and France, respectively. Moreover, the sample consists for 56.2% of passengers that live in the Netherlands[1] compared to 43.8% being international travellers and the destination of the samples are distributed between 56.5% to a Schengen destination compared to 43.5% to a non-Schengen destination. Figure 6 depicts the composition of the passengers in the sample size.

[1] Living in the Netherlands is defined by Schiphol Airport as one that inhabits a residence in the Netherlands for 100 or more days in advance of being interviewed

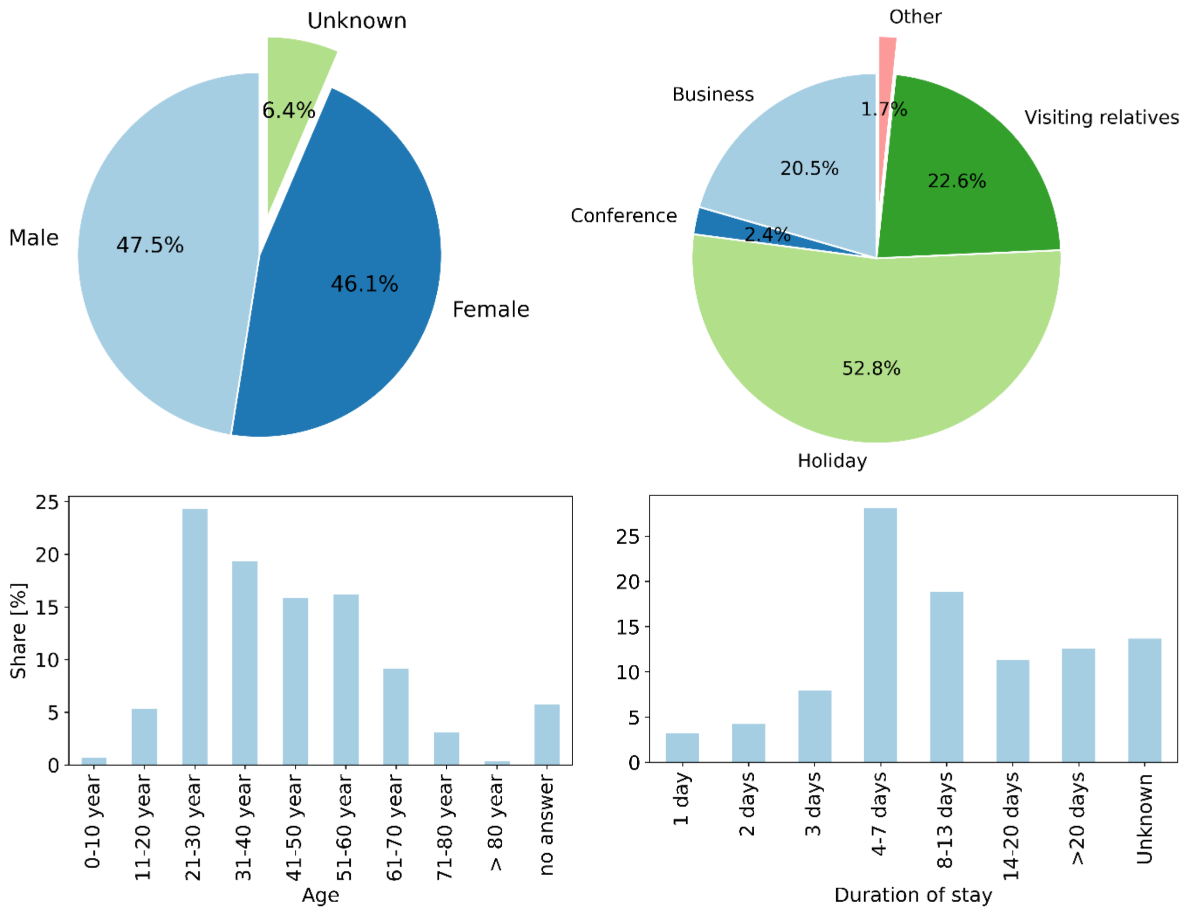


FIGURE 6: COMPOSITION OF PASSENGERS: TOP LEFT) GENDER; TOP RIGHT) TRIP PURPOSE; BOTTOM LEFT) AGE; AND BOTTOM RIGHT) DURATION OF TRIP

The most frequent trip purpose is holiday. Combined with visiting relatives, more than three-quarter of the passengers has a leisure purpose. The purpose share resembles in the Annual Report of Schiphol for 2023, underlining the representativeness of the dataset (Schiphol Group, 2024). Moreover, it should be noted that in the age distribution, 0.7% of the interviewees are aged under 10 years old. Their responses are untrustworthy and therefore excluded. Also, the distribution of the timing in flight departures of the respondents is presented in Figure 7.

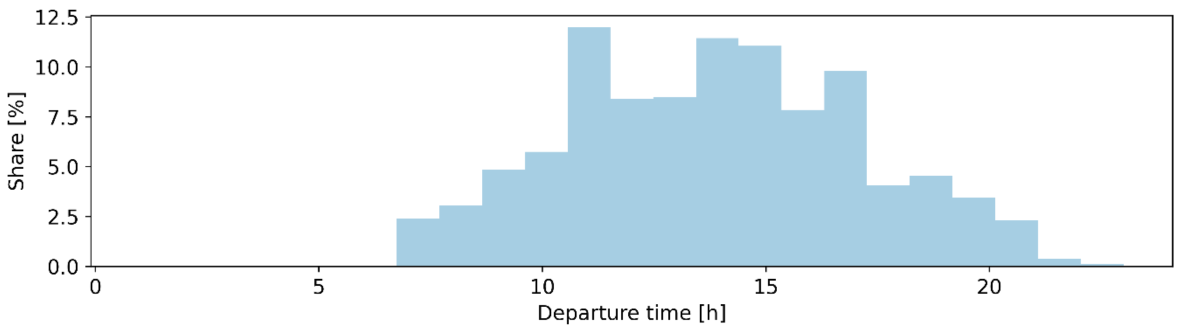


FIGURE 7: DISTRIBUTION OF TIMING OF FLIGHT DEPARTURE

From this distribution becomes clear that there are little to no respondents during the night hours. Although indeed less flights departure during the night, they are underrepresented due to the interview strategy. Respondents are only being asked during morning, afternoon and evening hours and not during the night. Also, it is observed that the peak hours for flight departures do not correspond fully with conventional commuting hours.

Figure 8 introduces the modal share of the passengers travelling towards Schiphol Airport. Literature suggested a segmentation between resident and international air travellers, as well as on trip purpose. Figure 8 also includes this segmentation.

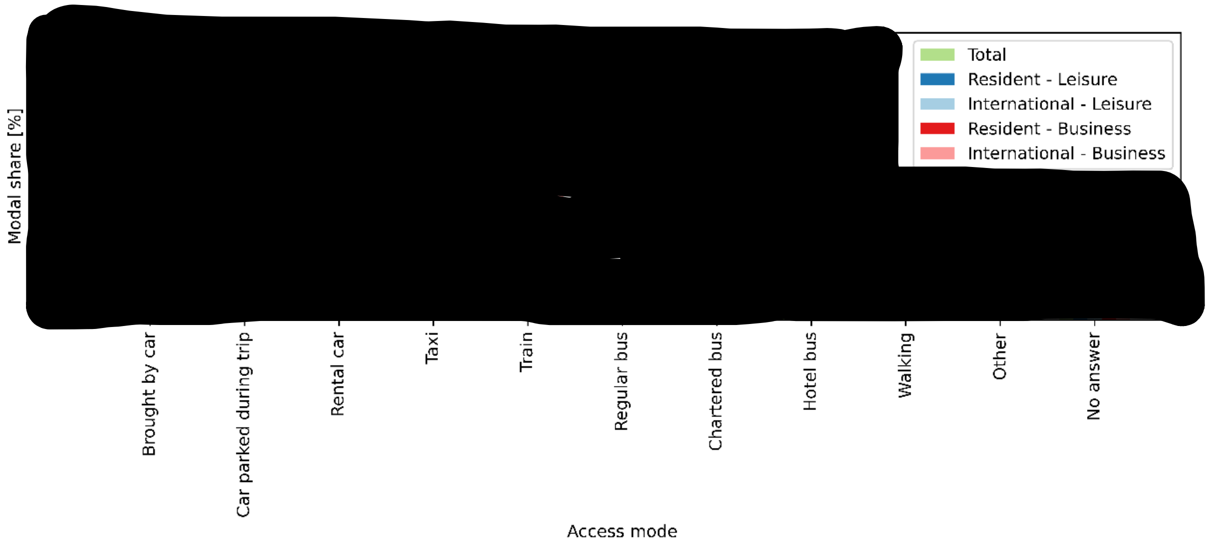


FIGURE 8: MODAL SHARE OF PASSENGERS

From this figure becomes apparent that the modal share is indeed different between resident and international air travellers. As expected, international travellers in general do not have a car at their disposal and as a result, they use private car modes less compared to resident air travellers. As a result, they use rental cars and taxis more often. For all groups the train is the most frequently used access mode. Business travellers in general use the taxi more often, while leisure travellers are more often brought by car.

Figure 6 and Figure 8 also introduce data deficiencies, including answers as 'unknown' and 'no answer'. In order for an individual response to be useful and allowing for the recreation of a reliable travel time and costs it is crucial that the access mode, the trip duration and a valid origin is known. Responses that do not include this data are excluded from further analysis. Responses that travel from foreign counties are represented by only a limited number of passengers, possible due to a boundary effect, resident passengers tend to use an airport within their national boundaries, regardless of travel distance (Zijlstra, 2020). Being able to change their mode choice could have a relatively large environmental impact, when shifted to a more sustainable mode. Nevertheless, the origin of this group is only known on country level. As a consequence, the travel time to Schiphol Airport cannot be reconstructed reliably and as a result the consideration between alternatives cannot be reconstructed in a reliable manner. Therefore, this group is also excluded from the analysis. Finally, 20% of the data is excluded from further consideration, so 43,676 responses are still left.

For the remaining responses it is assumed that a trip originates from the place of residence on PC4 level when this is situated in the municipality of the origin. Otherwise the municipality of the origin is used. For international air travellers there is not a higher level of detail of the origin than the municipality and therefore this spatial resolution is used for this group.

The spatial distribution of the known Dutch origins is provided in Figure 9. This figure illustrates that resident interviewees originate throughout the whole of the Netherlands, while international travellers originate specifically from Amsterdam and to a lesser extent from Rotterdam and The Hague.

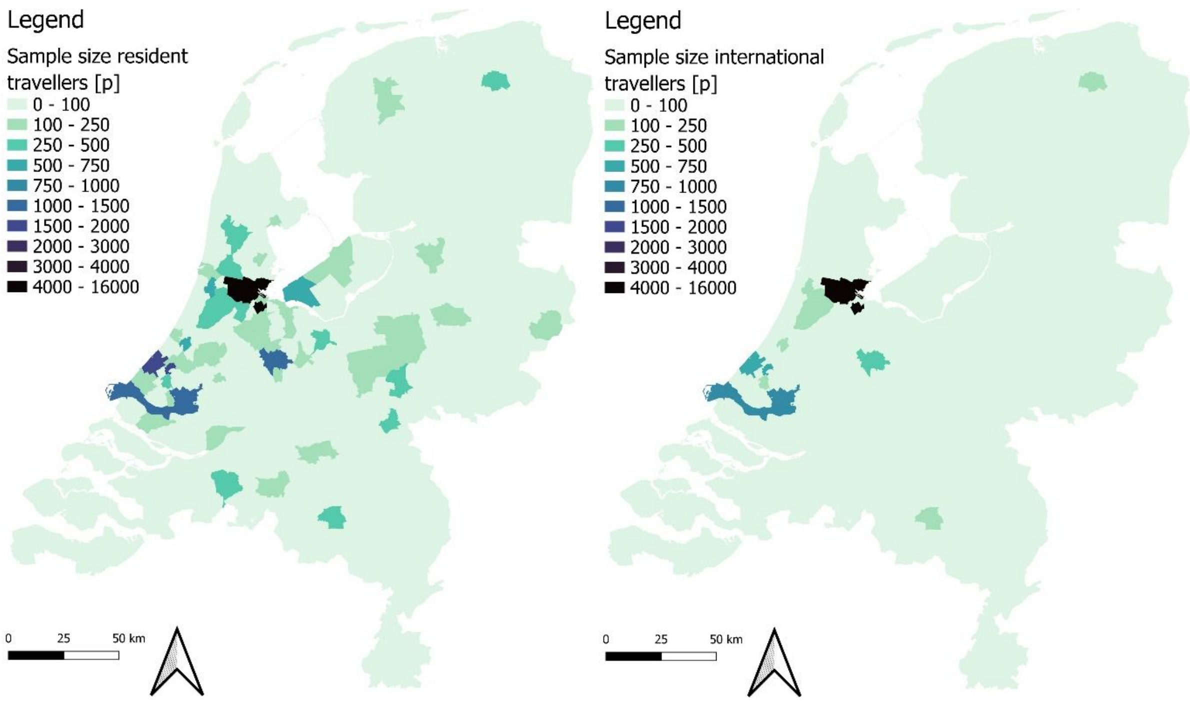


FIGURE 9: SPATIAL DISTRIBUTION OF SAMPLES FOR, LEFT) RESIDENT TRAVELLERS; RIGHT) INTERNATIONAL TRAVELLERS

Also, the relative spatial distribution of the resident samples to the population size of a municipality is presented in Figure 10. This figure indicates that relatively many respondents were interviewed originating from municipalities close to Schiphol Airport, as well as bigger cities throughout the remainder of the Netherlands.

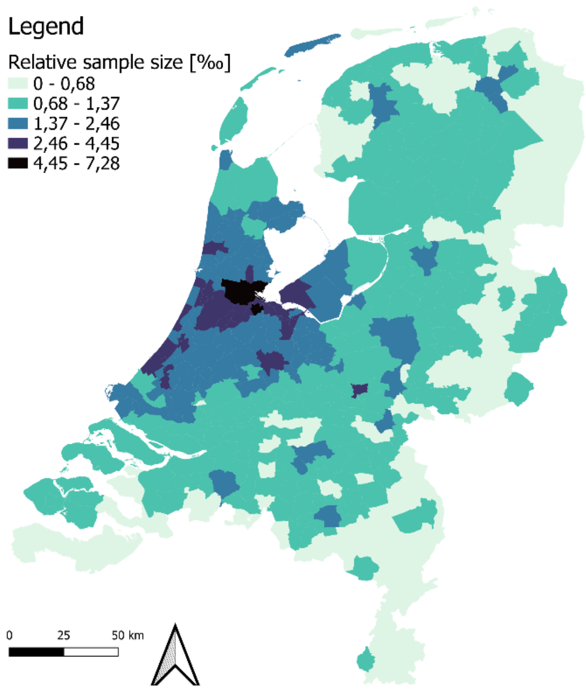


FIGURE 10: RELATIVE SPATIAL DISTRIBUTION OF SAMPLES FOR RESIDENT TRAVELLERS TO THE POPULATION SIZE OF A MUNICIPALITY

3.2.2. PERSONNEL DATA

Information on the travel behaviour of personnel is obtained using a revealed preference questionnaire. This data is gathered through a mobility study in 2017 among personnel across the full Schiphol areal, via an online questionnaire. Also, a study was conducted in 2022, but it was observed by Schiphol Airport that there was insufficient response. Therefore, the 2017 data is used in this study. The variables included in this dataset are presented in Table 6.

TABLE 6: VARIABLES INCLUDED IN THE MOBILITY STUDY OF 2017

Variable	Type of variable/alternatives
Origin	Categorical; PC4 code following CBS
Destination	Categorical; Schiphol Centrum, Schiphol Noordwest, Schiphol Noord, Schiphol Oost, Schiphol Technisch Areaal Oost, A Fokker Business Park/Skypark, Schiphol Rijk, Schiphol Zuidoost, Schiphol Zuid (9 working locations)
Type of working hours	Categorical; typical commute, shift work, shift work (only during the day), aviation work
Age	Categorical; below 18, 18-24, then classes of 5 year till 55+
Gender	Categorical; male, female
Commute frequency	Categorical; classes of 1 day between 1 and 5 days per week
Working from home at least one day/week	Categorical; yes, no but my employer provides the possibility, no but my employer does not prove this possibility
Access mode	Categorical; car driving alone, car passenger, carpooling, train, peak hour bus, regional bus, interliner bus, Rnet bus, motor, moped, bicycle, electric bicycle

The mobility study consists of 15,476 responses, which corresponds to around 22.5% of personnel working at the Schiphol areal in 2017 (68,660) following CBS (2019). The sample composition is presented in Figure 11.

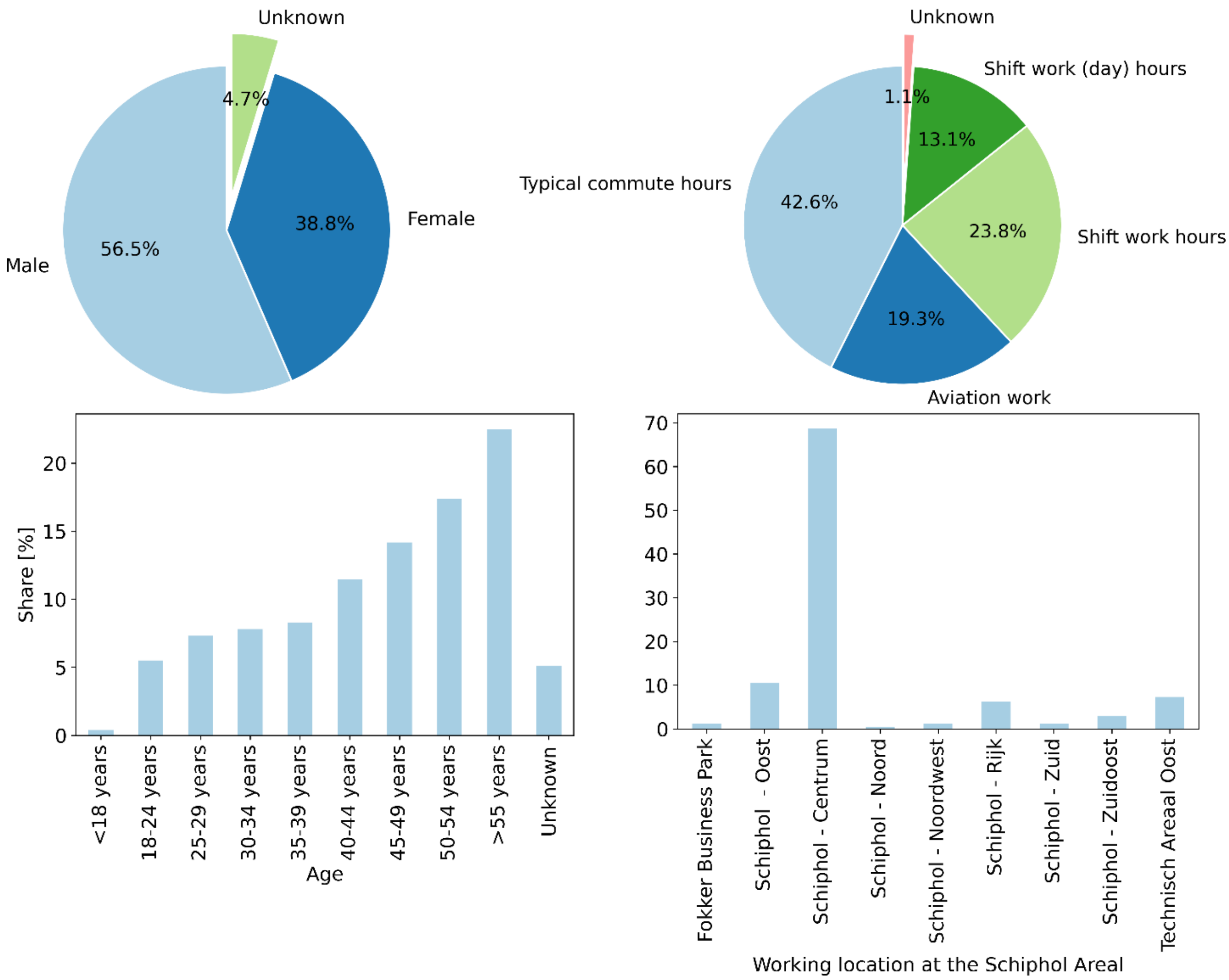


FIGURE 11: COMPOSITION OF PERSONNEL: TOP LEFT) GENDER; TOP RIGHT) TYPE OF WORKING HOURS; BOTTOM LEFT) AGE; BOTTOM RIGHT) WORKING LOCATION AT THE SCHIPHOL AREAL

This figure shows that a majority of personnel commutes during typical working hours, represented for 91.5% by office personnel. In contrast, both types of shift work are represented by a wider variety of job types, such as working in the catering industry, at the check-in desks and luggage handling. This figure also illustrates that personnel at Schiphol Airport is represented by relatively older individuals. Of course, there exists a larger range for the category older than 55 years, resulting in a visually misleading age overrepresentation. Nonetheless, the distributions presented in Figure 11 are representative for the total workforce. Furthermore, Schiphol Centum, the location where most jobs are situated, is the most prominent destination following the mobility study in 2017. Moreover, the modal share of personnel is provided in Figure 12. The modal share is segmented into the types of working hours as it is expected that the modal share differentiates between those.

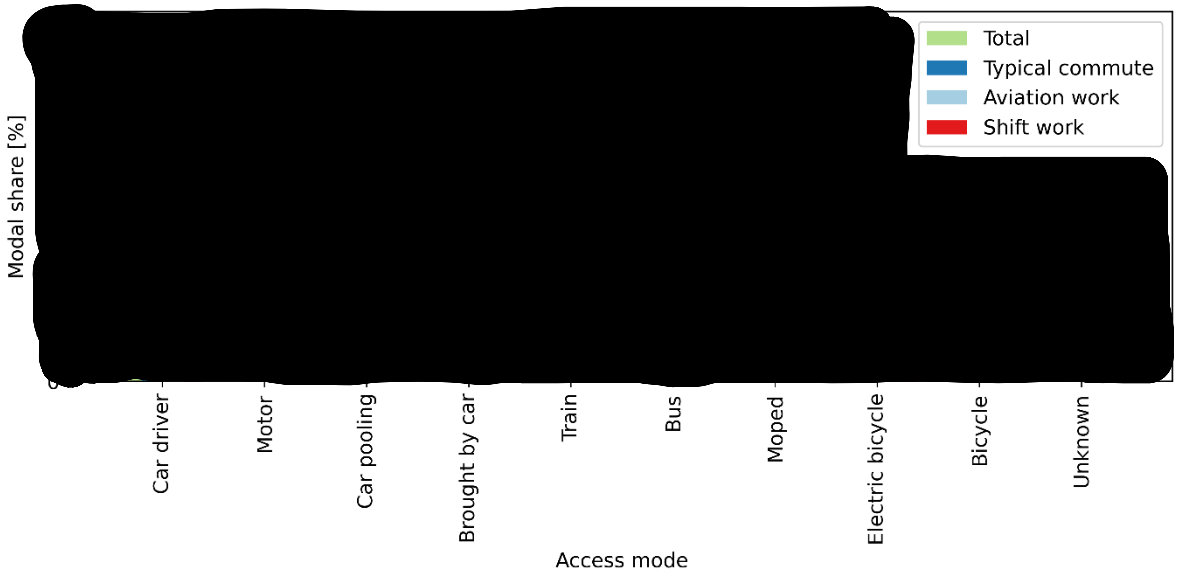


FIGURE 12: MODAL SHARE OF PERSONNEL

Only subtle differences between the modal share of different types of working hours are observed. Aviation workers often reside further from Schiphol Airport and as a result the use of moped and (electric) bicycle is low. In contrast, they use the car and the train more frequently. Especially, car drivers stand out, as their modal share is much higher for aviation workers, compared to other workers

Again, only responses with a valid origin, working location at the Schiphol areal and known access mode can be used. As a result, 5.9% of the responses had to be dropped resulting in 14,559 responses being included in the analysis. The relative spatial distribution of the personnel samples to the population size of a municipality is provided in Figure 13.

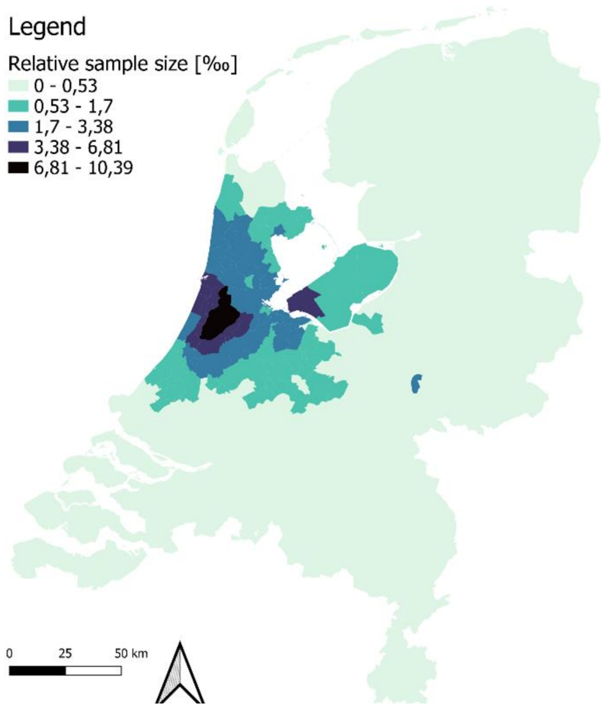


FIGURE 13: RELATIVE SPATIAL DISTRIBUTION OF PERSONNEL SAMPLES TO THE POPULATION SIZE OF A MUNICIPALITY

As expected, the fraction of personnel to the total number of inhabitants in 2022 is the highest close to Schiphol Airport. Also, the city of Almere has relatively many workers at Schiphol Airport (3.71‰). The most Eastern municipality that stands out is the municipality of Rozendaal (2.28 ‰). This relatively small municipality has four employers at Schiphol Airport, which is a relatively large share of their inhabitants of only 1,756 in 2022 (CBS, 2023b). This results in a distorted picture of the relative sample size.

4. RESEARCH METHODOLOGY

The methodology used in this study is visualised in Figure 14. Five steps are taken to achieve the research aim. These steps are displayed in chronological order. Each row represents a separate research question. The remainder of this section explains each step in more detail.

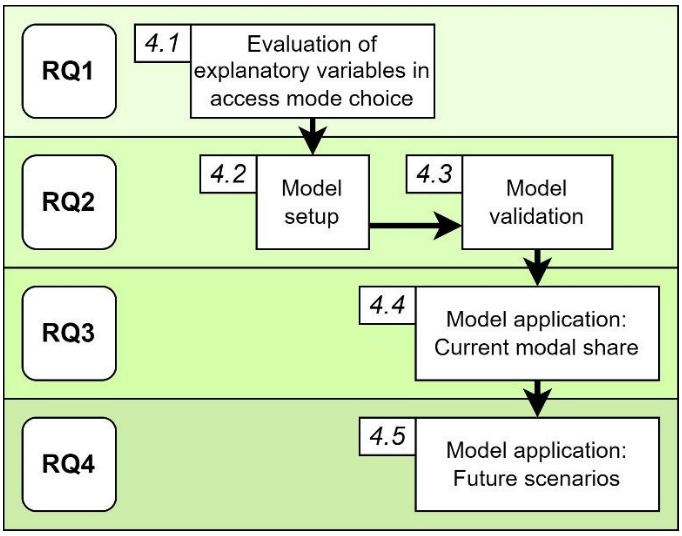


FIGURE 14: SCHEMATISATION OF THE METHODOLOGY

4.1. EVALUATION OF EXPLANATORY VARIABLES IN ACCESS MODE CHOICE

To set up a discrete choice model, a list of potential variables that explain airport access mode choice was needed. Potential explanatory variables were based on literature, given in Section 2.3. To use these variables, data on these variables should be available for the model parameter value estimation. Table 7 and Table 8 in Section 4.2.3 provide an overview of the selected explanatory variables for this study, specifically for passengers and personnel, respectively.

4.2. MODEL SETUP

A discrete choice model describes the relationship between different explanatory variables and the choice for an alternative in the choice set by utility functions for each alternative. This section describes how the parameters of a discrete choice model are estimated. Section 4.2.1 explains the type of discrete choice model that is employed. Section 4.2.2 introduces which alternatives are included in the choice set of this study. Then, the explanatory variables included in this study are outlined in Section 4.2.3. After that, the utility functions are specified (Section 4.2.4). Finally, the approach for dealing with heterogeneity between preferences of subgroups and the used software is provided (Section 4.2.5).

4.2.1. USE OF A DISCRETE CHOICE MODEL

A discrete choice model is used to quantify the extent to which explanatory variables influence access mode choice. However, these models are data demanding and require that this data is on an individual basis. Both datasets of Schiphol fulfil this requirement, making the use of a discrete choice model the obvious choice. From the family of discrete choice models, the MNL model is selected for this study. The MNL model is characterised by advantages, such as the ease of interpreting results and understanding the derivation of the final probabilistic choice function, while having relatively low computation times.

4.2.2. Choice Set

4.2.2.1. Passenger Specific

Following Section 3.2.1, many alternatives exist for access modes towards Schiphol Airport for passengers that are included in the RPM. The remainder of this section discusses why some of the existent access modes from the RPM are combined or split.

Multiple passenger parking sites at Schiphol Airport employ different parking rates. In this study, the parking sites are categorised in two categories, namely parking at one of the P3 parking sites and parking at Schiphol Centrum (P1, Valet, Excellence). The parking sites within the two categories are situated at the same proximity to the terminal building and have similar parking rate progressions depending on how many days a passenger's car is parked. Moreover, Schiphol Airport offers two distinct Kiss & Ride options, each listed separately in the choice set: parking at P1 and drop-off. These options differ in both cost and the out-of-vehicle time required to reach the terminal building. As Schiphol Airport considers measures at the Kiss & Ride drop-off specifically (Goudappel, 2024), a distinction between the two products is considered in the choice set. Next to that, all public transport alternatives were summarised to one public transport alternative. The rationale for this rose from the fact that transporting luggage is evenly inconvenient between the different public transport alternatives.

The access modes walking and hotel bus are excluded from this study. These modes are only used when someone used one of the hotels at Schiphol Centrum (walking) or one of the 18 hotels around Schiphol (hotel bus) (Stil, 2020). Of these passengers, only the PC4 or municipal code of the hotel is known and not where they originate before the hotel (Wolfers, 2024). Also, these modes represent only 0.9% and 1.5% of the modal share respectively and they have little influence on the traffic conditions around Schiphol Airport (Terlouw, 2024). Besides that, chartered busses are excluded from this study. Only little information is available about chartered busses, especially on their travel costs. Generally the travel time is higher than for cars. Gupta et al. (2008) used a factor of 1.7 to obtain chartered bus travel times from general travel times by car. Also, from the perspective of the STDM it is relatively uninteresting to estimate chartered busses, as their traffic volumes are relatively low (Terlouw, 2024). This corresponds with the RPM data, in which only 1.3% of the respondents used a chartered bus as access mode.

To conclude, for passengers the alternatives are public transport; car parking at Schiphol Centrum; car parking at P3; brought by car, parking; brought by car, drop-off; taxi and; rental car. By excluding the modes walking, hotel bus and chartered bus, 41,885 responses remain available.

4.2.2.2. Personnel Specific

Just as for passengers, multiple alternatives exist for personnel to travel to their working location within the Schiphol areal, which need grouping or splitting.

Firstly, car driving alone and motor are considered in the same category as they both consist of one person driving a private motorised mean of transportation. Besides that, in this study, a distinction between regular bicycles and the moped/electric bicycle combination, called slow motorised two-wheelers, is made. Both electric bicycles as mopeds have a substantial higher travel speed, compared to a regular bicycle (SWOV, 2022; van Velzen, 2024). This makes them also a viable alternative for personnel for longer travel distances. For personnel, public transport is split into bus and train. When travelling regularly to Schiphol Airport, is assumed that it makes a difference using bus or the train as main leg mode of transportation following their difference in comfort. Anderson et al. (2017) observed multimodal route choice in Copenhagen and indeed saw that there exists a difference in preferences for in-vehicle time for different types of public transport. Also, in the Dutch context, KiM (2023) found in a stated preference study that the values of travel time savings are substantially different for train compared to bus indicating a difference in disutility towards travel time/costs. The Mobility Spectrum provides the travel distance by train and by bus and based on this, the main leg transportation is estimated.

Moreover, the alternative 'brought by car' is excluded from this study. This type of transportation represents most of the time crew that is pickup from a nearby overnight stay facility and being brought to Schiphol Airport. These type of transportation are often arranged by employers rather than a choice made by an individual. As a result, access mode choice is not applicable for user of this alternative (Terlouw, 2024).

To conclude, for personnel the alternatives are car driver; carpooling; bicycle; slow motorised two-wheeler; train and; bus.

4.2.2.3. Availability of Alternatives

Depending on individual circumstances, only a subset of the mode alternatives may have been available to a respondent. Neither dataset explicitly includes questions related to the availability of alternatives. Also, implicit questions about alternative availability, as car ownership, are not included. When unknown, an alternative is assumed to be always available (Gunay & Gokasar, 2021).

For passengers the exception is public transport. While not explicitly mentioned in the dataset, an approximation of the availability can be made based on the flight timing, flight destination and origin. The first two are used to determine the arrival time at Schiphol Airport. Then, based on the arrival and the travel time the public transport availability is estimated. The Dutch Railways (NS) exploits night Intercity trains between Utrecht, Rotterdam, The Hague, Leiden, Amsterdam and Schiphol Airport on an hourly basis and as a result it was assumed that for passengers from these municipalities public transport is always available (NS, 2023). Public transport availability was not included for personnel as no timing of travelling was included.

4.2.3. Explanatory Variables

With the alternatives known within the choice set, the variables explaining the choice for these alternatives are introduced. First, the explanatory variables and how they are obtained are introduced in general, by the means of the categories variables related to the trip, origin and individual traveller. Thereafter, a detailed list of the explanatory variables for passengers and personnel specific is described.

4.2.3.1. Variables related to the Trip

Several trip related variables influencing access mode choice, such as travel time and costs, were introduced in Section 2.3.1. However, these variables are, besides trip purpose, not included in the datasets provided by Schiphol Airport. As a result, they can only be estimated by reconstructing the trip from the origin and the corresponding destination. The final destination for passengers is assumed to be the terminal building, while for personnel this depends on the destination provided in the questionnaire. Then, the trip is reconstructed for the chosen access mode, as well as the non-chosen alternatives. The remainder of this section introduces how the travel time, travel costs and travel time reliability are estimated in general.

Travel Time

Travel times are estimated using the Mobility Spectrum of Goudappel. This model provides travel time and distance for trips by car, public transport and bicycle for an average working day between the centroids of all administrative neighbourhoods ('buurten') in the Netherlands (Possel et al., 2020). Administrative neighbourhoods are a zonal division of CBS (2023b) and the address-weighted geographical centroid is considered as centroid. However, the origin of passengers and personnel is provided on a PC4 level (Section 3.2). To overcome the differences between divisions, the conversion table of CBS (2023c) was used. This conversion table demonstrates the relationship between administrative neighbourhoods and PC4 zones. Due to the large size of the administrative neighbourhoods, notable differences in public transport accessibility are observed, particularly in rural areas. The Mobility Spectrum disaggregates travel time by the time of the day (morning peak hour, evening peak hour and remainder of the day). For a detailed description on the methods for estimating the travel times I refer to Possel et al. (2020).

Travel Costs

To estimate travel costs for trips made by car, fuel costs and fuel consumption of a car are used. These costs are often used in airport access mode choice studies (Dissanayake & Jehanfo, 2009; Gunay & Gokasar, 2021), because car drivers have a relatively clear picture of the fuel costs (KiM, 2022b). Other costs, of owning and using a car, are not included, as 85% of Dutch car drivers structurally underestimates these costs (BNR & ANWB, 2014). The average fuel price over 2023 was € 1.921/L (CBS, 2023a). Autoweek (n.d.) estimated the average fuel consumption to be 6.29 km/L for benzine cars and 5.55 km/L for diesel cars. These two fuel types are still the most common in the Netherlands and their shares (71.1% and 17.9% respectively (RDW, 2023)) are used to estimate the average fuel consumption.

Travel costs by public transport are reflected by costs functions estimated by Goudappel. The train function is based on travel expenses of using the Dutch Railways and the bus function is an average of the different functions used by the largest bus carriers in the Netherlands. The cost functions are presented as follows, with C the travel costs in euros and d the travel distance in kilometres.

$$C_{train} = -0.0004\, d^2 + 0.2012\, d + 0.5718 \quad \text{Eq. 5}$$
$$C_{bus} = 0.0172\, d + 0.98 \quad \text{Eq. 6}$$

No direct costs are assumed to be associated with the use of the bicycle.

Travel Time Reliability

Travel time reliability plays an important role in the choice of access mode (KiM, 2023; König & Axhausen, 2002; Soza-Parra et al., 2022). This is especially the case for air travellers, who do not want to miss their flight. As a result, air travellers buffer time between desired arrival time and expected arrival time. Swierstra et al. (2017) used estimations of buffer times to estimate travel time reliability. However, the actual arrival time of travellers is unknown and thus it is not possible to estimate buffer times. Therefore, another widely used metrics from literature is used, the standard deviation of travel times (Soza-Parra et al., 2022; Swierstra et al., 2017). A high standard deviation indicates a large variability in travel times, hence a low travel time reliability.

In this study, car travel time reliability is estimated by using the travel time data obtained via Google Distance Matrix API. By doing so, it is possible to make use of the dynamically updated transportation network data and routing rules as maintained by Google (Google, n.d.; Wang & Xu, 2011). By specifying departure times and selecting the 'best guess' traffic model, Google predicts travel times based on historical data. Rothfeld et al. (2019) assessed access travel times of European airports, including Schiphol Airport, using five daily time stamps across three weekdays. However, this study observed that 22% of the respondents travelled on weekends. Thus, to analyse travel time variability, data for hourly departure intervals on Tuesdays, Thursdays and Saturdays are requested. Then, for personnel using typical commute hours only the two weekdays are considered when estimating the travel time variability (16,528 datapoints) and for passengers and all other types of personnel all days are considered (24,792 datapoints). It should be noted that specific assumptions and approaches employed by Google are unknown (Dumbliauskas et al., 2017; Rothfeld et al., 2019). This lack of data transparency makes it impossible to verify and validate the travel times estimated by Google directly (Wang & Xu, 2011).

A visual inspection of the spatial distribution of the travel time reliability by car (Figure 15) is used for verification purposes. This figure illustrates that, in general, municipalities further from Schiphol Airport exhibit greater travel time variation, which is a logical consequence of the longer travel time. However, the figure also indicates areas with a low travel time reliability as a result of congestion effects. When comparing the most congested areas in the Netherlands according to ANWB (n.d.), many similarities are observed, such as congested corridors like Breda – Rotterdam and the Eastern and Western entry roads to Eindhoven. This indicates that the estimated travel time reliability for cars is plausible. Note that the Google Distance Matrix API failed to retrieve travel times from the West-Frisian islands Vlieland and Schiermonnikoog.

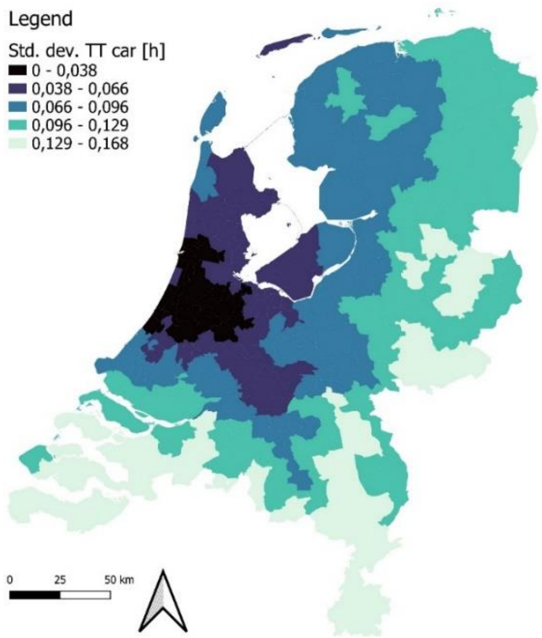


FIGURE 15: SPATIAL DISTRIBUTION OF TRAVEL TIME VARIABILITY

For public transport, travel time reliability is not included in this study. The Mobility Spectrum and the Google Distance Matrix API use scheduled travel times and do not consider any possible delays. As a result, they are not useful for determining travel time variability. Also, including fluctuations on the arrival times of trains at Schiphol Airport would not be an appropriate metric following the fact that way higher travel times could occur, due to missed transfers.

For bicyclists it is assumed that the travel time is not subjected to variability and therefore travel time reliability does not play a role.

4.2.3.2. VARIABLES RELATED TO THE ORIGIN

Following Gunay & Gokasar (2021), the distance from the origin location to public transportation facilities could play an important role in whether or not to choose for public transport. The same holds for the proximity to the highway network of the Netherlands. In both cases the distance provides an indication of the accessibility. CBS (2023d) provides the distance to train stations and highway onramps on a neighbourhood level in the Netherlands. Assuming that air travellers often have to take baggage with them, it is expected that passengers have a high disutility towards transfers. As a result, also the distance to an intercity station is considered as provided by CBS (2023d). Also, from an employee perspective living close to an (intercity) station affects the likelihood of choosing public transport (Limtanakool et al., 2006).

4.2.3.3. VARIABLES RELATED TO THE INDIVIDUAL TRAVELLER

This study utilises two data sources from Schiphol Airport for individual traveller variables: one for passenger data and another for personnel data. These datasets are introduced in Section 3.2. These datasets include a wide variety of explanatory variables, but not all that arose from literature (Section 2.3). For passengers, no information is included on the (household) income, access group size and carried luggage.

4.2.3.4. PASSENGER SPECIFIC

For passengers, the explanatory variables related to the individual traveller, to the origin and to the trip are described in detail in Table 7. Choices made with respect to the included explanatory variables are described in Appendix I.

The maximum travel time by car and public transport are higher than one would expect from domestic transportation in the Netherlands (see Table 7). These high travel times are observed when passengers originating from West-Frisian islands Terschelling and Vlieland, which have a ferry service of approximately 2.5 hours, explaining the high travel times. Moreover, adding up all averages of all categorical variables implemented as dummies, as for example age, results not always in a one, or 100%. This is caused by some responses that do not include that explanatory variable whatsoever.

4.2.3.5. PERSONNEL SPECIFIC

For personnel, the explanatory variables depends on the variables related to the individual traveller, to the origin and to the trip are described in detail in Table 8. Choices made with respect to the included explanatory variables are described in Appendix II.

The average and maximum travel time by bicycle and slow motorised two-wheeler are higher than expected for commuting (see Table 7). However, the average represents the travel time for all respondents, both the ones that choose a certain mode, but also the ones who do not choose the alternative.

TABLE 7: SUMMARY OF INCLUDED EXPLANATORY VARIABLES FOR PASSENGERS

Explanatory variable	Notation	Unit	Description	Applicable to …	Type of variable	Mean	Min	Max
Alternative specific constant	ASC	–		All modes		–	–	–
Trip variables								
Travel time								
(In-vehicle) travel time PT	$ivTT_{PT}$	h	Travel time between origin and Schiphol Airport	Public transport	Continuous	1.21	0.41	8.15
(In-vehicle) travel time car	$ivTT_{car}$	h	Travel time between origin and Schiphol Airport	All modes except public transport	Continuous	0.65	0.11	6.43
Travel costs								
Travel costs PT	C_{PT}	€	Travel costs between origin and Schiphol Airport	Public transport	Continuous	10.07	1.78	35.28
Travel costs car	C_{car}	€	Travel costs between origin and Schiphol Airport	Both car parking options	Continuous	6.63	0.92	29.69
Travel costs taxi	C_{taxi}	€	Travel costs between origin and Schiphol Airport	Taxi	Continuous	104.77	14.58	469.32
Parking costs								
P3	C_{parkP3}	€	Average parking costs for parking facilities at P3	Car parking at P3	Continuous	[redacted]	[redacted]	[redacted]
Schiphol Centrum	C_{parkSC}	€	Average parking costs for parking facilities at Centrum	Car parking at Schiphol Centrum	Continuous	[redacted]	[redacted]	[redacted]
Travel time reliability								
Car network	R	h	Standard deviation of travel times between origin and Schiphol Airport	All modes except public transport	Continuous	0.07	0	0.17
Origin variables								
Accessibility								
Distance to highway	$D_{highway}$	km	Network distance between origin and highway onramp	All modes except public transport	Continuous	2.08	0.1	37.7
Distance to train station	$D_{station}$	km	Network distance between origin and train station	Public transport	Continuous	3.79	0.2	53.1

Distance to intercity station	$D_{ICstation}$	km	Network distance between origin and intercity station	Public transport	Continuous	6.76	0.4	63.8
Individual characteristics variables								
Trip purpose								
Purpose, holiday	$P_{holiday}$	–	When the main purpose of a trip is holiday related	All modes	Binary; 1 if true	0.57	0	1
Purpose, visiting relatives	P_{visrel}	–	When the main purpose of a trip is to visit relatives	All modes	Binary; 1 if true	0.24	0	1
Purpose, business	$P_{business}$	–	When the main purpose of a trip is business related	All modes	Binary; 1 if true	0.21	0	1
Purpose, conference	$P_{conference}$	–	When the main purpose of a trip is conference related	All modes	Binary; 1 if true	0.02	0	1
Duration of stay								
Duration of stay, 1-3 days	TD_{1-3}	–	1-3 days away (residents) or in the Netherlands (internationals)	All modes	Binary; 1 if true	0.18	0	1
Duration of stay, 4-13 days	TD_{4-13}	–	4-13 days away (residents) or in the Netherlands (internationals)	All modes	Binary; 1 if true	0.53	0	1
Duration of stay, 14->20 days	$TD_{14->20}$	–	14->20 days away (residents) or in the Netherlands (internationals)	All modes	Binary; 1 if true	0.27	0	1
Other individual characteristics								
Resident traveller	RT	–	Someone living in the Netherlands during the past 100 days	All modes	Binary; 1 if true	0.59	0	1
Schengen destination	DS	–	Whether or not the first destination is Schengen	All modes	Binary; 1 if true	0.44	0	1
Night travelling	NT	–	Whether or not someone has to arrive at the airport between 22:00 and 7:00	All modes	Binary; 1 if true	0.14	0	1
Gender	G	–	–	All modes	Binary; 1 if female	0.46	0	1
Age, 11-20	Age_{11-20}	–	Age between 11-20	All modes	Binary; 1 if true	0.05	0	1
Age, 21-30	Age_{21-30}	–	Age between 21-30	All modes	Binary; 1 if true	0.24	0	1
Age, 31-60	Age_{31-60}	–	Age between 31-60	All modes	Binary; 1 if true	0.51	0	1
Age, 61->80	$Age_{61->80}$	–	Age between 61->80	All modes	Binary; 1 if true	0.03	0	1

TABLE 8: SUMMARY OF INCLUDED EXPLANATORY VARIABLES FOR PERSONNEL

Explanatory variable	Notation	Unit	Description	Applicable to …	Type of variable	Mean	Min	Max
Alternative specific constant	ASC	–		All modes		–	–	–
Trip variables								
Travel time								
(In-vehicle) travel time PT	$ivTT_{PT}$	h	Travel time between origin and specific working location	Train and bus	Continuous	0.87	0.19	3.75
(In-vehicle) travel time car	$ivTT_{car}$	h	Travel time between origin and specific working location	Car driver and carpooling	Continuous	0.50	0.05	2.63
(In-vehicle) travel time bike	$ivTT_{bike}$	h	Travel time between origin and specific working location	Bicycle	Continuous	1.99	0.07	11.80
(In-vehicle) travel time slow motorised two-wheeler	$ivTT_{SMTW}$	h	Travel time between origin and specific working location	Slow motorised two-wheeler	Continuous	1.67	0.06	9.89
Travel costs								
Travel costs PT	C_{PT}	€	Travel time between origin and specific working location	Train and bus	Continuous	8.23	1.78	34.06
Travel costs car	C_{car}	€	Travel time between origin and specific working location	Car driver and carpooling	Continuous	4.77	0.92	31.02
Travel time reliability								
Car network	R	h	Standard deviation of travel times between origin and Schiphol areal	Car driver and carpooling	Continuous	0.05	0	0.16
Origin variables								
Accessibility								
Distance to highway	$D_{highway}$	km	Network distance between origin and highway onramp	Car driver and carpooling	Continuous	1.72	0.2	6.7
Distance to train station	$D_{station}$	km	Network distance between origin and train station	Train and bus	Continuous	3.88	0.3	46.4
Distance to intercity station	$D_{ICstation}$	km	Network distance between origin and intercity station	Train and bus	Continuous	7.99	0.4	50.2

Individual characteristics variables								
Type of working hours								
Type of working hours, office	W_{office}	–	When the type of work is office work	All modes	Binary; 1 if true	0.44	0	1
Type of working hours, shift	W_{shift}	–	When the type of work is shift work	All modes	Binary; 1 if true	0.24	0	1
Type of working hours, shift (day)	$W_{shift(day)}$	–	When the type of work is shift work during the day	All modes	Binary; 1 if true	0.13	0	1
Type of working hours, aviation	$W_{aviation}$	–	When the type of work is aviation work	All modes	Binary; 1 if true	0.18	0	1
Working onsite								
Working from home	WfH	–	Whether or not someone works from home at least one day per week	All modes	Binary; 1 if true	0.26	0	1
Working from Schiphol, <1-1 day	$WfS_{<1-1}$	–	Working on location between less than 1 day and 1 day per week	All modes	Binary; 1 if true	0.10	0	1
Working from Schiphol, 2-4 day	WfS_{2-4}	–	Working on location between 2 days and 4 days per week	All modes	Binary; 1 if true	0.47	0	1
Working from Schiphol, 5->5 day	$WfS_{5->5}$	–	Working on location between 5 days and more than 5 days per week	All modes	Binary; 1 if true	0.43	0	1
Working locations								
Working at Schiphol Centrum	L_{SC}	–	Working at Schiphol Centrum or Schiphol Zuid	All modes	Binary; 1 if true	0.69	0	1
Working outside Schiphol Centrum	L_{BU}	–	Working at Schiphol Noord-West, Noord, Oost, Zuid-Oost, Rijk, or Technisch Areaal Oost or Fokker Business Park	All modes	Binary; 1 if true	0.31	0	1
Other individual characteristics								
Gender	G	–	–	All modes	Binary; 1 if female	0.40	0	1
Age, <18-24	Age_{18-24}	–	Age between <18-24	All modes	Binary; 1 if true	0.06	0	1
Age, 25-39	Age_{25-39}	–	Age between 25-39	All modes	Binary; 1 if true	0.24	0	1
Age, 40-54	Age_{40-54}	–	Age between 40-54	All modes	Binary; 1 if true	0.46	0	1
Age, >55	$Age_{>55}$	–	Age between >55	All modes	Binary; 1 if true	0.24	0	1

4.2.4. UTILITY SPECIFICATION

Now, the available alternatives in the choice sets for both passengers and personnel are identified, along with the variables that explain the choice for each alternative. Then, the explanatory variables are used to define a utility function per alternative. The specification of the utility function per alternative is not trivial and is an iterative process. In every iteration, the parameters in the model are re-estimated and the performance of the model is judged by the means of its goodness-of-fit using the adjusted McFadden R^2 (Section 4.3.3). After many trials the adjusted McFadden R^2 is expected to become stable indicating that the model fit does no longer improve substantially and the final estimate is obtained. Note that the estimation is done on 80% of the dataset, as 20% is reserved for validation purposes (Section 4.3.4). The remainder of this section first describes the alternative specific constant included in the utility functions. Secondly, the identification of interaction variables is introduced. Then, the effect of the level of significance on the utility function specification is described in Section 4.2.4.3. Finally, the approach in specifying the utility function is introduced.

4.2.4.1. ALTERNATIVE SPECIFIC CONSTANT

Per alternative, there exists an alternative specific constant (ASC). This constant captures the systematic differences in utility of alternatives that are not captured by the observed variables. With J alternatives, only $J - 1$ ASC's can be entered into the model (Lancsar et al., 2017). As a result, one of them is normalised to zero (Train, 2009, Chapter 2). In this study, the most frequently occurring alternative is set to zero, being public transport and car driver for passengers and personnel, respectively.

4.2.4.2. INTERACTION VARIABLES

Interaction variables are included in the utility function to capture the combined effect of two or more explanatory variables. Potential interaction variables are identified using an association rules analysis, as suggested by Changpetch & Lin (2013). The basic idea is to explore relationships between subsets of independent variables. The more often a subset occurs in the dataset, the more likely the subset functions as an interaction variable (Agrawal & Srikant, 1994). It should be noted that not all subsets are meaningful and might have a high support, because of the categorical nature of some of the variables. Judgement on how meaningful certain subsets are remains important.

4.2.4.3. SIGNIFICANCE LEVEL

The estimated parameters are judged on their statistical significance in explaining access mode choice. A confidence level of 95% is employed as often used in literature (Colovic et al., 2022; Dissanayake & Jehanfo, 2009; Gunay & Gokasar, 2021; KiM, 2023; Pels et al., 2001; Roh, 2013). Considering the large sample size of both the passenger and personnel dataset, many variables are also statistically significant on a 99% confidence interval. To allow for comparison, both confidence levels are reported in the results. It should be noted that statistical significance is used only as a guide (Parady & Axhausen, 2023). There might be estimates which are not statistically significant but may give insights in the effects of variables on access mode choice. Especially, when they play a key role in the calculation of a scenario or in the validation of the model, such as travel costs and travel time.

4.2.4.4. UTILITY SPECIFICATION PHASES

The approach for specifying the utility function and inclusion of explanatory variables is done via three phases, as visualised in Figure 16, which should culminate in an extensive evaluation of the solution space. For each model (# model), the figure presents the included access modes and explanatory variables. The exploration phase is used to verify the behaviour of the model when different (definitions of) alternatives are included.

Then, two approaches are used to identify statistically significantly variables explaining access mode choice: the top down and bottom up approaches. Including all possible explanatory variables results in an overfitted model (Chowdhury & Turin, 2020). Two approaches are employed in this study to counteract the selection bias, as the selection of explanatory variables is based on statistical evidence, as well as expert judgement. From the two obtained models, the one with the highest explanatory power, based on the adjusted McFadden's R^2 is selected for further analysis. The remainder of this section dives deeper in the methods of the top down and bottom up approach, respectively.

In the top down approach, also called backwards elimination, all explanatory variables are included in the beginning and, following a step-by-step approach, parameters are removed, based on their statistical significance, starting with the ones with the highest P-value (Borboudakis, 2019; Chowdhury & Turin, 2020; KiM, 2023). This approach allows for the assessment of joint predictive of variables. However, when a variable is excluded from the model, this approach does not allow for re-entering (Chowdhury & Turin, 2020).

In contrast, the bottom up approach, in this form also called stepwise selection, starts with an empty model and adds new variables during every iteration. Variables that are, or become, statistically insignificant are then excluded. This process of entering and removal of variables from the model allows for a high flexibility (Chowdhury & Turin, 2020).

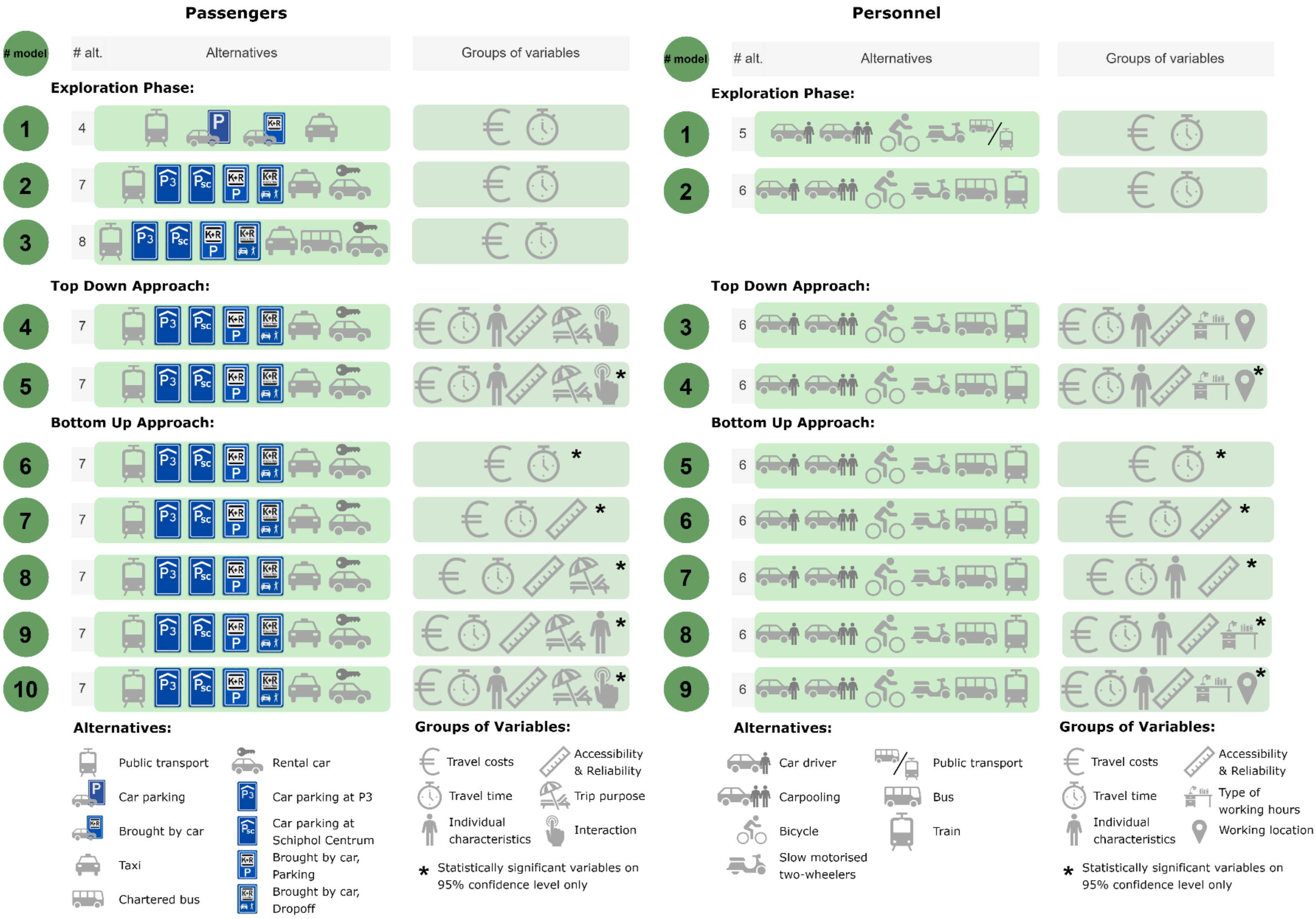


FIGURE 16: SUMMARY OF APPROACH FOR INCLUDING VARIABLES FOR PASSENGERS AND PERSONNEL

4.2.5. DEALING WITH HETEROGENEITY BETWEEN PREFERENCES OF SUBGROUPS

Often, an estimated global model does not fit well with the data according to certain performance criteria, due to heterogeneity between preferences of subgroups. There exist two methods for dealing with this heterogeneity. On the one hand, by including dummy variables of all subgroups and on the other hand by splitting the global model into segments for which better fitting models are estimated, also called segmentation. Dummy variables are relatively easy to implement and allow for variation within one estimated model, however their inclusion provides less understanding into different subgroups (Short, 2017).

In theory, unlimited (combinations of) segments could be considered, as long as a substantial sample remains available (Fosgerau & Bierlaire, 2007). As a result, the segmentations are limited to those found in literature only. Table 9 shows the evaluated segmentations. Due to the existence of different datasets, different choice sets and different travel behaviours as stressed by Choo et al. (2013), models for passengers and personnel are always separated.

TABLE 9: INCLUDED SEGMENTATIONS

Applicable to	Segmentation	Literature	Included as
Passengers	Residence	(Gupta et al., 2008; Hess & Polak, 2006)	Dummy
	Purpose (business, conference, holiday, visiting relatives)	(Choo et al., 2013; Ellis et al., 1974; Gupta et al., 2008; Hess & Polak, 2006; Roh, 2013; Sobieniak et al., 1979)	Dummy
	Residence **X** purpose (business, leisure)	(Hess & Polak, 2006)	Segmented model
Personnel	Type of working hours (typical commute, shift, shift (day), aviation)	(Tsamboulas et al., 2012)	Dummy
	Working location	Schiphol Airport	Dummy

4.2.6. SOFTWARE

The MNL model is estimated using the software package Biogeme. Biogeme is an extension of Python specifically designed for research in discrete choice models, and in particular GEV models (Bierlaire, 2009; Lancsar et al., 2017). Biogeme has a list of predefined discrete choice models, but also allows for the writing of more complex models using the well-known Python language (Ali et al., 2019). More recently, Apollo, a powerful freeware package of R, is introduced, known for its fully customisability (Hess & Palma, 2019). The flexibility associated with Apollo comes with the drawback of slow computation times for large sample sizes (Molloy et al., 2021). As Biogeme and Apollo have similar advantages and Biogeme is the faster of the two, Biogeme was chosen.

4.3. MODEL VALIDATION

Schlesinger et al. (1979, p. 1) define validation as "substantiation that a computerized model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model." In this study, validation of the explanatory power refers to what extent the estimated model parameters are able to explain access mode choice. Lancsar et al. (2017) stresses the importance of including various checks to ensure the internal validity of estimated discrete choice models. Therefore, the models are validated using four approaches. The fifth subsection introduces how the last validation step, the comparison of market shares, is applied to specific segments.

4.3.1. PARAMETER SIGNS

The directions of the signs, positive or negative, of the estimated parameters are compared to the directions found in literature.

4.3.2. VALUE OF TIME SAVINGS

Estimated marginal effects are a powerful interpretative device (Lancsar et al., 2017; Parady & Axhausen, 2023; Wulff, 2015). In the case of transport studies the marginal effects are called the value of time savings. The value of time savings is computed by dividing the estimated parameter for the travel time by the estimated parameter for the travel costs for a certain alternative access mode. This value of time savings indicates how much euro an individual, on average, is willing to pay to reduce its travel time by one hour. The value of time savings are compared with KiM (2023). KiM (2023) specifically mention value of travel time savings for four access modes to airports, namely car parking, car Kiss & Ride, taxi and public transport, for the Dutch context specifically.

4.3.3. ADJUSTED MCFADDEN R^2

In this study, the adjusted McFadden R^2 is used to give insight into the goodness-of-fit. This value indicates how much of the variation in the dependent variable is explained by the model (Bayaga, 2010; Hu et al., 2006). In contrast to ordinary R^2 values, adjusted R^2 values account for the number of explanatory variables and are therefore preferred. There exist multiple different adjusted R^2 values, such as for example the Efron's, McFadden and the Nagelkerke R^2 value. The adjusted McFadden R^2 value has the advantage that it does not only consider the variability in the independent variables explaining the variation in the dependent variable but also considers the improvement of the model from the null model to the fitted model. In this case, the null model is a model estimating the dependent variable without any independent variables (Hu et al., 2006; Train, 2009, Chapter 3). This performance metric is often used in literature and allows for easy interpretation (Choo et al., 2013; Dissanayake & Jehanfo, 2009; Gunay & Gokasar, 2021; Jou et al., 2011). The closer the value is to one, the higher the explanatory power of the model. Nonetheless, it should be noted that the (adjusted) McFadden R^2 tends to be considerably lower than the more conventional R^2 values and values between 0.2 and 0.4 already indicate a decent to excellent fit (Hensher et al., 2015, Chapter 7; McFadden, 1975). It should also be noted that the McFadden R^2 is dataset specific. This means that it is not possible to compare different models that use different (subsets of) datasets. On top of that, this incomparability already holds when on the same dataset, different sets of alternatives are considered (Ugba & Gertheiss, 2023).

4.3.4. MARKET SHARES

The comparison of estimated market shares with the observed ones gives an indication of the ability of the model to determine the access mode choice correctly based on the explanatory variables. Parady et al. (2021) mention that in the validation of discrete choice models in transportation, researchers rely too much on goodness-of-fit statistics. They stress the use of out-of-sample testing, using data that is not used in the estimation, to validate the reproducibility of the model. In this study only one dataset for passengers and one for personnel is available, and thus internal validation via data splitting is suggested. In this approach the dataset is randomly split into an estimation or training dataset and a validation or test dataset. Then, the model parameters are estimated on the estimation dataset (see Section 4.2.4) and are validated on the validation dataset. In this study an 80/20 split is used as in multiple other mode choice studies (Glerum et al., 2014; Golshani et al., 2018; Hasnine & Habib, 2018; Ma et al., 2015; Mahmoud et al., 2016).

Then, performance measures indicate how well the model can estimate a certain outcome in the validation dataset. An often used metric is the percent correctly estimated choices, also called accuracy (Parady et al., 2021; Train, 2009, Chapter 3), as used in, for example, Colovic et al. (2022). However, this approach violates the meaning of choice probabilities, as the researcher does not have enough information to predict the decision maker's choice. The researcher only has enough information about the probability of the alternatives under consideration. Train (2009, Chapter 3) mentions that by stating choice probabilities, each alternative would be chosen a certain portion of the time, when repeating the choice situation numerous times. Using this knowledge, the full market share for the validation dataset can be estimated and compared to the actual market share of the observed choices in the validation dataset. Following Parady et al. (2021), this is the third most used validation approach in transportation studies, however its frequency of use in airport access mode studies remains relatively low. This approach is summarised in Figure 17. Thus, the final comparison is between the frequency of the alternatives in the "*Choice*" column, marked in bold, and the sum of the probabilities as predicted by the estimated model, marked by the column "*Probability*" in bold. Moreover, 95% confidence intervals are added to give an indication of the representativeness of the sample, compared to the population following the approach described in Pots (2017) assuming a binomial distribution.

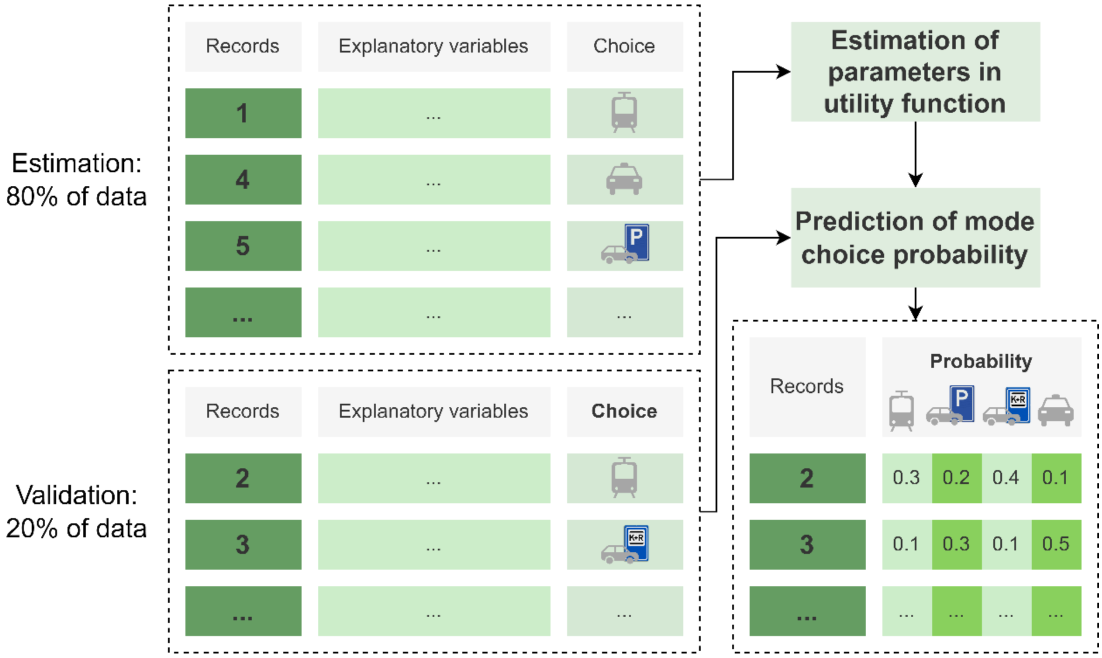
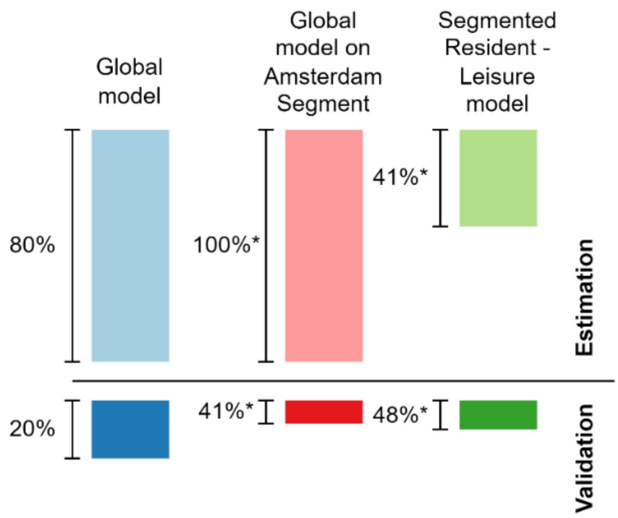


FIGURE 17: SCHEMATISATION OF COMPARING OBSERVED MARKET SHARES WITH ESTIMATED MARKET SHARES

4.3.5. Segmented Market Shares

When splitting the validation dataset into specific segments, it is possible to evaluate the global model performance for a more specific segment. In that case, the estimated model remains the same, but the validation set is filtered for a specific segment as visualised in Figure 18 for the Amsterdam segment in blue. In that case, only origins from the municipality of Amsterdam are in the validation set.

When estimating a model for a specific segment, the corresponding responses are isolated from the estimation dataset. Then, to validate the estimated market share, the same filtering criteria are used to isolate specific responses from the validation dataset as visualised in Figure 18 for the resident – leisure segment in red. In that case 41% of the estimation dataset of the global model are resident – leisure travellers and are therefore included in the estimation dataset for a separate model. Then, the resident – leisure travellers present in the validation dataset (48% of the validation dataset) are used to validate this separate model.



** Percentage compared to the estimation/validation dataset of the global model*

FIGURE 18: ILLUSTRATION OF INCLUDED DATA IN THE ESTIMATION AND VALIDATION CONTEXT FOR DIFFERENT SEGMENTS

4.4. MODEL APPLICATION: CURRENT MODAL SHARE

The estimated models for passengers and personnel are useful for estimating the modal split for the whole population rather than just the sample dataset. The population is created by multiplying every response with a weight. This weight is estimated by Schiphol Airport and indicates how many passengers or personnel an individual response represents. It is based on a wide range of characteristics of the response, including the timing of the day and different flight characteristics for passengers and the working location for personnel (Wolfers, 2024).

4.5. MODEL APPLICATION: FUTURE SCENARIOS

Schiphol Airport is not only interested in the modal share of the model in a base year, but also in the modal share under conditions of potential policy and infrastructural measures. Estimated discrete choice models are convenient for this purpose (Lancsar et al., 2017). In order to underline the importance of including access mode choice in the model and how wide their impact is, three future scenarios are considered. The future scenarios are developed based on literature available on possible future measures at Schiphol Airport and after consultation with Schiphol Airport.

It should be noted that these scenarios are treated purely theoretically. No stated preference study or pilot is executed in this study and the results of the model should only give an indication of the mode shift. As a result, validation of the scenarios is relatively hard, due to limited literature available related to the scenarios. The remainder of this section introduces the designed future scenarios, increasing the parking fare at P3 with 10% and the projected passenger and workforce growth in 2040.

4.5.1. SCENARIO 1: 10% PARKING FARE INCREASE AT P3

Schiphol Airport increases its parking fares almost annually. In 2023 the increase was 5% (de Groot, 2023). Schiphol Airport does this, for example, to compensate for inflation. Following the aim of Schiphol Airport to reduce car usage in order to decrease emissions, a further increase of parking fares is plausible.

In this scenario, specifically the fares at P3 are selected following various reasons. Firstly, the few parking services at P3 are more similar to each other in comfort and price rate, than at Schiphol Centrum. Moreover, by increasing only one parking facility, a potential shift between the two different parking sites can be analysed. Lastly, by only increasing the fares of the cheapest parking site, the increased parking fares remain within the already encountered parking fares.

4.5.2. SCENARIO 2: PASSENGER PROJECTION FOR 2040

Schiphol Airport estimates a substantially higher growth for international departing passengers, compared to resident departing passengers for 2040. Table 10 demonstrates the fraction between resident and international travellers and their main trip purpose in 2009, 2017, 2023 and how this potentially evolves to 2040, assuming a linear extrapolation of the passenger volumes. Following a different preference in access mode choice, a shift in the modal share is expected.

TABLE 10: PASSENGER SEGMENT SHARE

Year	Source	R-L [%]	I-L [%]	R-B [%]	I-B [%]
2009	RPM dataset (2009)	43.9	24.5	16.9	14.8
2017	RPM dataset (2017)	43.5	34.4	13.5	8.7
2023	RPM dataset (2023)	43.1	32.7	11.1	13.1
2040 (expected)	Linear extrapolation	42.8	37.7	8.7	10.8

4.5.3. SCENARIO 3: PERSONNEL PROJECTION FOR 2040

Schiphol Airport expects a surge in personnel volumes following real estate developments around the Schiphol areal for 2040. Hagens et al. (2017) present these developments and distinguish between approved plans and uncertain plans. It is assumed that the growth in approved office space as presented in the document is indicative for the growth in workforce. Following this assumption, the surge in workforce is presented in Table 11.

TABLE 11: PROJECTED PERSONNEL GROWTH FOR 2040

Schiphol Areal	Workforce in 2017	Projected workforce in 2040
Schiphol – Centrum	40,647	49,608
Schiphol – Oost, Technisch Areaal Oost	8,400	11,053
Schiphol – Noord	695	5,695

5. MODEL ESTIMATION RESULTS

This section presents the model estimation results, corresponding to the first four steps of the methodology. Section 5.1 presents the global model for passengers. First, the parameter value estimations of the discrete choice model are presented and interpreted. Then, the model is validated using the four steps presented in Section 4.3. Thereafter, the findings are summarised in a synthesis. In Section 5.2 similar results are presented, but then for personnel.

5.1. PASSENGER SPECIFIC

For passengers, the parameters in a discrete choice model are estimated and presented in Table 12. The model is estimated based on 80% of the dataset, the estimation dataset. The other 20% is used for validation purposes as discussed later in this section. The corresponding variable definitions are presented in Table 7 and utility function specifications are provided in Appendix III. The parameter value estimates, as presented in Table 12, indicate the change in utility, for a certain alternative, when a certain variable increases by 1 unit. For example, the utility for public transport decreases by 1.36, when the travel time for public transport increases by 1 hour.

For passengers, segmented models for resident – leisure, resident – business, international – leisure and international – business segments were considered, as an improved fit and market share compared to the global model was expected. However, this improvement was not observed, and as a result, the global model is presented here and used for further analysis. The model estimation results of the segmented models are presented in Appendix IV. The parameter value estimates of the global model presented in Table 12 illustrate a negative sign for travel time, travel costs and parking costs. Besides that, trip purpose, especially holiday and business purposes, and residence affect access mode to a large extent, indicating that access mode choice differs significantly between the above-mentioned segments. Also, other individual characteristics as gender and age have significant influence on access mode choice.

The remainder of this section discusses the interpretation of the parameter value estimates and corresponding signs in more detail and shows the results of the four validation steps as introduced in Section 4.3. This section concludes with a synthesis of the most important findings concerning the explanation of passenger access mode choice.

TABLE 12: RESULTS OF THE GLOBAL MULTINOMIAL LOGIT MODEL FOR PASSENGERS

Parameter [unit]	Value	Rob. t-stat.
Alternative Specific Constant [-]		
Public transport		
Car parking at P3	-6.06	-26.99
Car parking at SC	-5.36	-29.17
Brought by car, parking	-3.76	-30.26
Brought by car, drop-off	-1.19	-12.56
Taxi	-1.09	-10.24
Rental	-3.33	-23.18
Travel Time [1/h]		
Public transport	-1.36	-18.18
Car parking at P3	-1.33	-6.93
Car parking at SC	-1.39	-5.54
Brought by car, parking	-3.13	-16.85
Brought by car, drop-off	-3.89	-20.61
Taxi	-0.98	-3.62
Rental	-2.91	-15.23

Parameter [unit]	Value	Rob. t-stat.
Travel Costs [1/€]		
Public transport	-0.10	-8.20
Car parking at P3	-0.07	-3.67
Car parking at SC	-0.09	-3.89
Taxi	-0.03	-13.97
Parking Costs [1/€]		
P3	-0.006	-8.16
Schiphol Centrum	-0.005	-11.43
Travel time reliability [1/h]		
Car network	3.54	3.94
Accessibility [1/km]		
Distance to highway		
Distance to train station		
Distance to Intercity train station		

Note: The parameters reported in the table were statistically significant on a 99% confidence level. When marked by an asterisk (*) the parameters was only statistically significant on a 95% confidence level – ***Table continues on next page***

Parameter [unit]	Value	Rob. t-stat.
Trip purpose		
Holiday [boolean]		
Public transport	0.22*	2.07
Car parking at P3		
Car parking at SC		
Brought by car, parking	-1.37	-16.10
Brought by car, drop-off	-1.26	-12.11
Taxi	0.46	4.46
Rental		
Visiting relatives [boolean]		
Public transport	0.17*	2.55
Car parking at P3		
Car parking at SC		
Brought by car, parking		
Brought by car, drop-off		
Taxi		
Rental		
Business [boolean]		
Public transport	-0.58	-6.15
Car parking at P3		
Car parking at SC		
Brought by car, parking	-1.42	-10.89
Brought by car, drop-off	-1.08	-13.57
Taxi	0.35	3.63
Rental	0.51	4.47
Conference [boolean]		
Public transport		
Car parking at P3		
Car parking at SC		
Brought by car, parking		
Brought by car, drop-off	-0.75	-6.79
Taxi		
Rental		
Trip purpose interaction variables		
Resident traveller - Business [boolean]		
Public transport		
Car parking at P3		
Car parking at SC		
Brought by car, parking		
Brought by car, drop-off		
Taxi	-0.69	-7.28
Rental	-1.33	-4.68
Resident traveller - Holiday [boolean]		
Public transport	-1.35	-13.91
Car parking at P3		
Car parking at SC		
Brought by car, parking		
Brought by car, drop-off	0.27	2.55
Taxi	-1.54	-12.83
Rental	-1.78	-7.32

Parameter [unit]	Value	Rob. t-stat.
Duration of stay		
4-13 days[2] [boolean]		
Public transport		
Car parking at P3		
Car parking at SC		
Brought by car, parking		
Brought by car, drop-off	0.32	6.67
Taxi	0.12	2.88
Rental	0.25	2.81
14->20 days[2] [boolean]		
Public transport		
Car parking at P3		
Car parking at SC		
Brought by car, parking	1.20	17.66
Brought by car, drop-off	0.74	13.92
Taxi	0.49	9.49
Rental	0.60	5.52
Other individual characteristics		
Resident traveller [boolean]		
Public transport		
Car parking at P3	1.80	11.42
Car parking at SC	2.64	14.48
Brought by car, parking		
Brought by car, drop-off		
Taxi	-0.34	-5.14
Rental	-2.11	-11.42
Schengen destination [boolean]		
Public transport	0.21	4.00
Car parking at P3		
Car parking at SC	0.15*	2.16
Brought by car, parking	-0.61	-6.93
Brought by car, drop-off	-0.27	-4.89
Taxi	-0.22	-3.88
Rental		
Night travelling [boolean]		
Public transport		
Car parking at P3		
Car parking at SC		
Brought by car, parking	-0.24	-2.67
Brought by car, drop-off	-0.12	-2.65
Taxi	0.31	6.56
Rental		
Gender [boolean]		
Public transport		
Car parking at P3	-0.42	-5.81
Car parking at SC	-0.16	-3.00
Brought by car, parking	0.47	7.22
Brought by car, drop-off		
Taxi		
Rental	-0.45	-5.65

Note: The parameters reported in the table were statistically significant on a 99% confidence level. When marked by an asterisk (*) the parameters was only statistically significant on a 95% confidence level – ***Table continues on next page***

[2] Staying for 1-3 days being the reference group

Parameter [unit]	Value	Rob. t-stat.
Age 11-20 years[3] [boolean]		
Public transport	0.29	4.1
Car parking at P3		
Car parking at SC	-0.88	-5.08
Brought by car, parking	1.03	8.47
Brought by car, drop-off	0.47	5.78
Taxi		
Rental		
Age 21-30 years [boolean]		
Public transport	0.64	6.14
Car parking at P3	-0.69	-4.35
Car parking at SC	-0.64	-4.84
Brought by car, parking	0.79	6.42
Brought by car, drop-off	0.36	3.31
Taxi	0.31	2.83
Rental		

Parameter [unit]	Value	Rob. t-stat.
Age 61->80 years [boolean]		
Public transport	-0.26	-6.08
Car parking at P3		
Car parking at SC		
Brought by car, parking		
Brought by car, drop-off		
Taxi	0.17	3.14
Rental		
Summary statistics		
McFadden R^2		0.380
Adjusted McFadden R^2		0.379

Note: The parameters reported in the table were statistically significant on a 99% confidence level. When marked by an asterisk (*) the parameters was only statistically significant on a 95% confidence level

5.1.1. Interpretation of Results

Travel Time, Travel Costs & Parking Costs

For all modes, the negative sign on travel time and costs parameters in Table 12 demonstrates that an increase in impedance between the origin and Schiphol Airport decreases the utility, as expected from literature (Gunay & Gokasar, 2021; Gupta et al., 2008; Hess & Polak, 2006; Jou et al., 2011; Roh, 2013; Sobieniak et al., 1979). For parking costs for both alternatives, the same sign is observed as in Jou et al. (2011).

When comparing the magnitude of the travel time estimates, it is observed that the alternatives for which no costs are included in the model, brought by car and rental, generally have a more negative travel time elasticity (-2.91 or lower compared to -1.39 or higher). Due to the high correlation between travel time and costs, it is possible that the travel time parameter also incorporates the travel costs of these alternatives to a certain extent.

Public transport users have the highest price elasticity (-0.10) and taxi users having the lowest (-0.03). The latter is also observed in Colovic et al. (2022) and Jou et al. (2011) and this corresponds to the hypothesis that passengers using a taxi typically have a higher budget and are therefore less affected by changes in price and luxurious products in general are often associated with low price elasticities (Theiss & Noll, 2022). The same holds true for parking costs. Passengers parking at Schiphol Centum, the more costly parking site, are less sensitive to price changes according to the model (-0.005 compared to -0.006). It was hypothesised that parking at Schiphol Centrum also would have a lower elasticity for travel costs compared to parking at P3, but the results do not show this (-1.39 compared to -1.33). Roh (2013) found that higher price elasticities are observed for long travel distances and passengers parking at P3 generally travel 29% further compared to parking at Schiphol Centrum, potentially causing the higher elasticity for the priciest alternative.

Travel Time Reliability

The travel time variability for the car network has a positive parameter sign (3.54). This suggests that the higher the uncertainty in travel time by car, the more likely it is to choose one of the alternatives that include a car. This might sound unexpected, however Sweet & Chen (2011) also found that the influence of travel time reliability by car is limited and does not play a role in travel decision-making. As a result, it is plausible that the travel time reliability behaves as a proxy for a wide variety of other variables, such as car dependency. The spatial distribution of car dependency in the Netherlands is similar to the one of travel time reliability, where destinations further from Schiphol Airport, and the Randstad in general, are often associated with higher car dependencies (KiM,

[3] Aging between 31 and 60 being the reference group

2022a). Despite not representing travel time reliability, this parameter contributes positively to the model performance as it allows for a better estimation of the access mode choice, depending on the distance to Schiphol Airport.

Trip Purpose

Trip purpose, and especially holiday and business purposes, has a substantial influence on the likelihood of choosing a certain access mode. However, visiting relatives and conference purposes barely influence access mode choice, possibly due to a relatively low sample size.

Business travellers are more likely to rent a car or to use a taxi as found in literature (Choo et al., 2013; Hess & Polak, 2006). Both alternatives are more expensive, but also correspond with high flexibility and comfort.

Holiday passengers are less likely to be brought by car. A plausible explanation for this might be that passengers with a holiday purpose are travelling with their family or a full travel group. As a result, it is harder to find a driver to bring them to the airport or there is no space available in the car. Literature included access group size, but none makes a distinction between different types of car modes (Gupta et al., 2008; Jehanfo & Dissanayake, 2009). Specifically for resident – holiday travellers, the use of public transport, taxi and rental cars is less preferred, following their negative sign. Whereas taxi and rental car might be explained by being a resident traveller in general, public transport is possible negatively perceived by Dutch travellers following the inconvenience of luggage and the availability of a car.

Duration of Stay

The duration of stay has an influence on the access mode choice. For medium (8-13 days) to long (14->20 days) trips, the preferred access mode choice is both types of being brought by car. Parking options are not considered for the duration of stay as the correlation between parking costs and duration of stay is high. Nonetheless, the increased parking fees might explain why being brought by car becomes more preferred for longer trips.

Individual Characteristics

Parameter value estimates show that resident travellers are more likely to park their car at P3 or Schiphol Centrum. This group is more likely to own a car and therefore the preference for parking is argumentative. In contrast, international travellers are more likely to use a taxi or a rental car, as also observed in Gupta et al. (2008).

When having a Schengen destination, it is less likely for passengers to be brought by car or by taxi. Following their positive sign, public transport and car parking at Schiphol Centrum are more likely. Flights to Schengen destinations are often for trips with a shorter duration of stay. Therefore, parking at Schiphol Centrum is relatively cheap.

During the night, taxi is the most favourable access mode choice, possibly due to their 24 hour availability. As expected, being brought by car is less favoured, as it is harder to find someone willing to drive. Also, the ratio between the two alternatives for being brought by car is plausible. Being brought by car, parking has a higher magnitude (-0.24) compared to drop-off (-0.12), as it is most convenient for the driver to have a speedy drop-off during unpleasant hours.

In this study, gender is included as a dummy variable, in which a 1 represents being a female. Positive signs for being brought by car indicate a higher likelihood of usage by women, whereas negative demonstrate the opposite, as for car parking and rentals. This is in line with the findings in Sobieniak et al. (1979) and Gupta et al. (2008) and the latter contribute this effect to the lesser inclination of female travellers to drive to the airport, as airports generally have a busy and complex road network.

People older than 61 years old are shown to be more likely to use taxi compared to the reference age group, whereas they are less likely to use public transport as in correspondence with Choo et al. (2013). Especially elderly might have troubles transporting luggage via public transport, causing this inconvenience. In contrast, the two youngest age groups included in this study (11-20 and 21-30 years old) are shown to be less likely to use car parking as access mode, possibly due to low vehicle ownership (CBS, 2021). Therefore, they use public transport, as also found in Gupta et al. (2008). The 11-20 years old age group demonstrates even higher magnitudes for being brought by car, especially parking, compared to public transport (1.03 compared to 0.29). A potential cause could be that parents prefer to bring their children to the airport.

5.1.2. VALIDATION OF EXPLANATORY POWER

The previous section introduced the parameter (sign) interpretation. The model has, in general, parameters with a plausible sign, that are in line with literature in most of the cases. In the remainder of this section, the results of the other three validation approaches are presented, namely the value of time savings, the goodness-of-fit and the market shares.

VALUE OF TIME SAVINGS

Table 13 presents the comparison of the value of time savings for passengers, by comparing the values found in this study and in a stated preference study by KiM (2023), specifically for airport access/egress. Again, the value of time savings represents how much euro passengers are willing to pay to reduce their travel time by 1 hour for a certain access mode. Since travel costs are not considered for both alternatives of brought by car, it is not possible to compute the value of time savings for this access mode.

TABLE 13: VALUE OF TIME SAVINGS COMPARISON PASSENGERS

Access Mode	Global MNL [€/h]	KiM (2023) [€/h]
Public transport	13.2	9.11
Car parking at P3	18.0	15.57
Car parking at Schiphol Centrum	14.8	
Brought by car	-	11.86
Taxi	36.6	21.51

The values of time estimated in this study are generally higher compared to ones obtained by KiM (2023). KiM (2023) employed a stated preference study, while this study uses revealed preference data, possibly explaining the difference. Nonetheless, most studies conclude that stated preference studies in general have higher elasticities compared to revealed preference studies, as stated preference studies overcome unawareness and habit effects (Wardman, 2022). However, respondents in a stated preference study make their choices based solely on the variables presented, whereas in reality, additional factors also influence their decisions. Also, the design of the study influences the values of time savings and the ratio between the values obtained in stated and revealed preference studies significantly according to Li et al. (2020) and Hensher (2004). The latter found that a high number of explanatory variables, as also employed in this study, often results in higher values of time savings. Additionally, the ratio between the different access mode alternatives is similar with the price elasticities for travel costs, with the most costly alternative having the highest value of time savings. This alternative is often chosen by those with a higher budget and therefore value their time of transportation highly.

GOODNESS-OF-FIT

The model has an adjusted McFadden R^2 of 0.379, which corresponds with a decent to an excellent fit (Hensher et al., 2015, Chapter 7; McFadden, 1975). When including solely travel time and costs, the adjusted McFadden R^2 drops to 0.318, indicating that travel time and costs are important in explaining access mode choice for passengers. Nonetheless, including additional variables resulted in a better fit, hence a higher explanatory power. Also, the adjusted McFadden R^2 of the global model is relatively stable. When estimating the model, using the same explanatory variables, for 40% and 20% of the data, adjusted McFadden R^2's of 0.379 and 0.378 are obtained, respectively.

MARKET SHARES

For the validation dataset, the estimated modal share is compared with observed choice frequencies. Figure 19 presents this comparison for the entire validation dataset and shows that the model performs well in estimating the total market share. This figure also includes 95% confidence intervals to indicate the representativeness of the sample compared to the population. Despite the good model performance, considering 19.6 million annual departing passengers, small errors in the market shares can result in a large absolute number of passengers for whom the access mode choice is estimated wrong. For example, the model underestimated the modal share of passengers using the taxi by only 0.41%. When projecting this error onto the annual departing passengers, it results in a misidentification of the access mode choice of approximately 80,000 departing passengers.

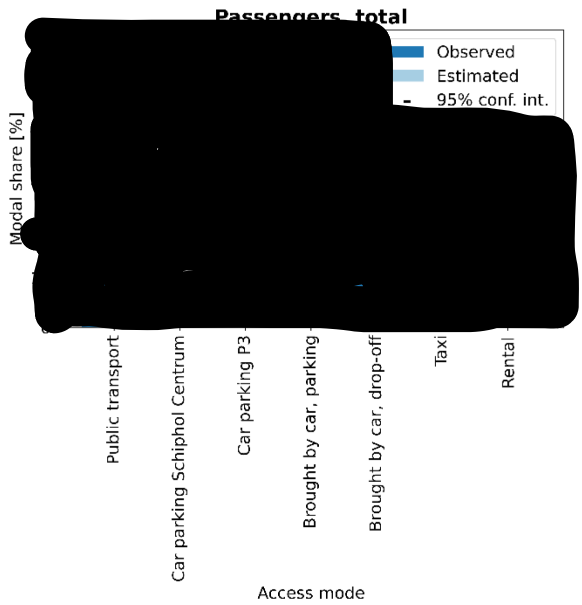


FIGURE 19: PASSENGER TOTAL MARKET SHARE

Figure 20 presents the estimated and observed modal share for specific segments of the passengers market. Figure 20 (left) presents modal share for passengers with an origin in Amsterdam and Figure 20 (right) presents the modal share for passengers with an origin more than 75 kilometre driving from Schiphol Airport. The latter simulates origins outside the Randstad area, who, in general, are more bounded to the use of cars (KiM, 2022a). These estimated modal shares are based on a subset of the validation dataset. For the two specific market segments 3,430 and 1,980 responses remained available in the validation dataset, respectively.

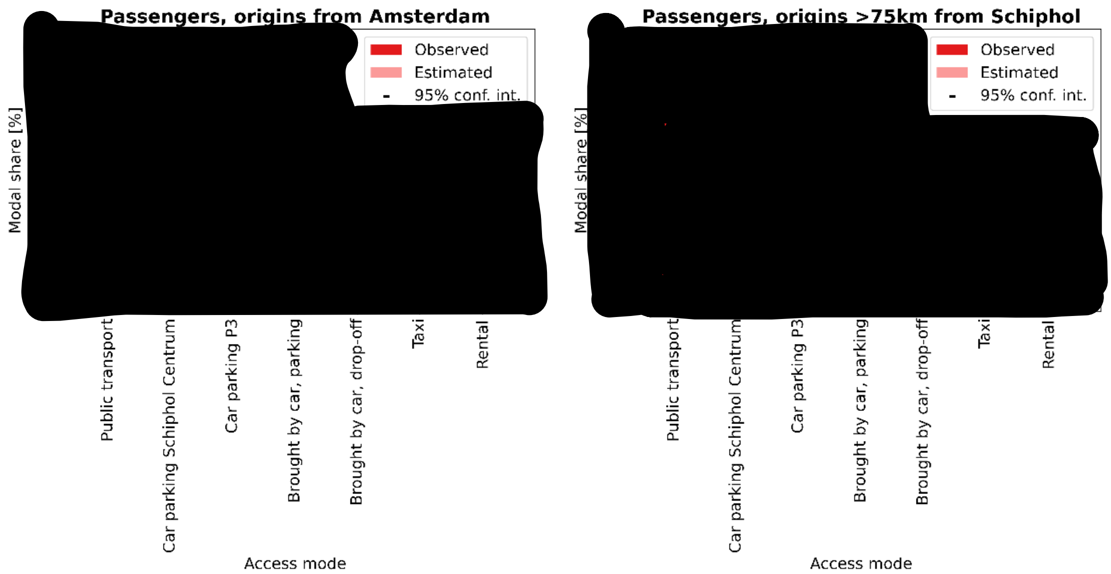


FIGURE 20: SPECIFIC PASSENGER MARKET SHARES FOR LEFT) ORIGINS FROM AMSTERDAM; AND RIGHT) ORIGINS FURTHER THAN 75 KM FROM SCHIPHOL AIRPORT

The estimated modal shares correspond less to the observed market share segments compared to the total market share. Nonetheless, proportions in the market shares are very well captured.

In line with what was expected, for passengers travelling from Amsterdam to Schiphol Airport, the car share is very low, due to the presence of a well-established public transport network. Also, on these short distances, the taxi remains a prominent access mode choice, especially for international travellers. Nonetheless, the high share in taxi usage is not well-captured by the model, potentially due to a high share of international travellers travelling from Amsterdam (70.3% of the validation dataset), while the model is estimated on a more balanced estimation dataset for all origins in the Netherlands.

For distances larger than 75 kilometres, the use of a private car is much more prominent compared to the Amsterdam segment. This underlines car dependency outside of the Randstad area and therefore also substantiates why travel time reliability might act as a proxy for a car dependency as described in KiM (2022a).

There exists a difference in access mode choice between resident and international air travellers, as well as between trip purposes, following Figure 8, and the estimation for the modal share is presented in Figure 21.

FIGURE 21: SPECIFIC MARKET SHARE FOR TOP LEFT) RESIDENT – LEISURE; TOP RIGHT) INTERNATIONAL – LEISURE; BOTTOM LEFT) RESIDENT – BUSINESS; AND BOTTOM RIGHT) INTERNATIONAL – BUSINESS

The figure illustrates that the model estimates the modal share well for all segments, potentially due to the inclusion of dummy variables for both the residence as the trip purpose. The figure indicates that international travellers indeed have a very low share of car parking, whereas a high share of taxis and rentals is observed. Resident – holiday travellers have a relatively high share of being brought by car, drop-off.

There exist seasonal differences in aircraft movements with quarter three being the busiest and quarter one being the calmest (Schiphol Group, 2023). The estimated and observed market shares for quarter 1 and 3 are visualised in Figure 22. For the two specific market segments still 2,242 and 2,030 responses remained available in the validation dataset respectively.

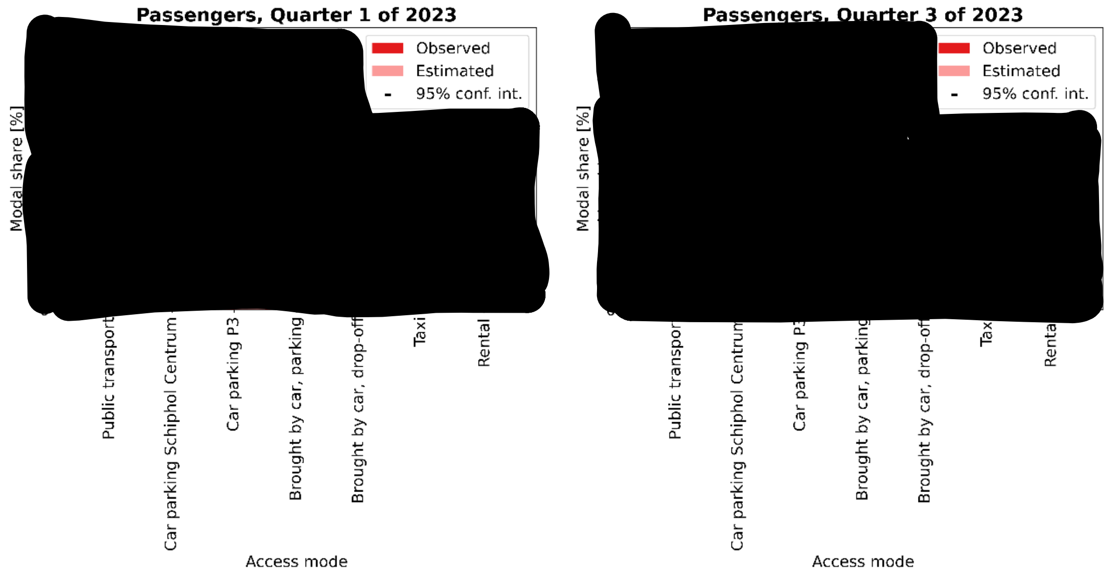


FIGURE 22: SPECIFIC MARKET SHARES FOR LEFT) QUARTER 1 OF 2023; AND RIGHT) QUARTER 3 OF 2023

Figure 22 shows that, in general, proportions in the market shares are well captured for both quarters.

5.1.3. SYNTHESIS

This section introduced the model estimation for passengers. There exists a wide variety of variables that contribute to explaining access mode choice of passengers. The model exhibits an excellent fit and the market shares indicate that the model is not only able to estimate the total modal share accurately, but also on segments based on residence, trip purpose, origin and quarter of the year. Nonetheless, it should be noted that minor misidentifications result in a large absolute number of passengers for whom the access mode is estimated wrong. Therefore, the model should not be used to estimate absolute volumes (for specific segments) individually.

5.2. PERSONNEL SPECIFIC

Table 14 presents the parameter value estimation results for the global personnel model. Again, the global model is estimated on 80% of the dataset, while the remaining 20% is used for validation purposes. The corresponding variable definitions are presented in Table 8 and utility function specifications are provided in Appendix V. As with passengers, the parameter value estimates in Table 14 indicate the change in utility for a specific alternative when a certain variable is increased by 1 unit.

In contrast to passengers, no segmented models for personnel are considered, as for the segments suggested in literature (type of working hours) do not show substantial differences in modal share, hence the global model is used for further analysis. The parameter value estimates for the global model presented in Table 14 illustrate that a higher impedance for travel time, travel costs and accessibility results in a lower utility for a specific alternative. Other important explanatory variables are the type of working hours, the working location, age and gender. Nonetheless, working from home and the number of days working onsite have little impact on the access mode choice.

The remainder of this section first describes the interpretation of the parameter value estimates and corresponding signs in more detail, then dives deeper into the steps to validate the model. This section concludes with a synthesis of the most important findings.

TABLE 14: RESULTS OF THE GLOBAL MULTINOMIAL LOGIT MODEL FOR PERSONNEL

Parameter [unit]	Value	Rob. t-stat.
Alternative Specific Constant		
Car driver		
Car pooling	-2.51	-17.01
Bicycle		
Slow two-wheelers	-1.16	-5.93
Train		
Bus		
Travel Time [1/h]		
Car driver	-2.33	-3.76
Car pooling	-4.96	-15.81
Bicycle	-4.39	-22.62
Slow two-wheelers	-4.70	-18.30
Train	-2.20	-10.68
Bus	-1.61	-3.77
Travel Costs [1/€]		
Car driver	-0.26	-5.43
Car pooling		
Train	-0.20	-7.82
Bus	-0.57	-8.65
Accessibility [1/km]		
Distance to highway	-0.09	-3.24
Distance to train station	-0.06	-5.17
Distance to Intercity train station	-0.03	-4.49
Travel time reliability [1/h]		
Car network		

Parameter [unit]	Value	Rob. t-stat.
Type of working hours		
Office work [boolean]		
Car driver	-0.40	-4.89
Car pooling	-0.43	-3.80
Bicycle		
Slow two-wheelers		
Train	0.36	3.70
Bus		
Shift work (day) [boolean]		
Car driver	-0.42	-6.15
Car pooling		
Bicycle		
Slow two-wheelers		
Train		
Bus		
Shift work [boolean]		
Car driver		
Car pooling		
Bicycle		
Slow two-wheelers	0.98	6.57
Train		
Bus		

Note: The parameters reported in the table were statistically significant on a 99% confidence level. When marked by an asterisk (*) the parameters was found only statistically significant on a 95% confidence level – ***Table continues on next page***

Parameter [unit]	Value	Rob. t-stat.
Aviation work [boolean]		
Car driver		
Car pooling	-1.95	-7.37
Bicycle		
Slow two-wheelers		
Train		
Bus	-0.33*	-2.16
Working onsite		
Working from home [boolean]		
Car driver		
Car pooling		
Bicycle		
Slow two-wheelers		
Train		
Bus		
Working <1-1 days onsite[4] [boolean]		
Car driver		
Car pooling		
Bicycle		
Slow two-wheelers		
Train		
Bus		
Working 5->5 days onsite[4] [boolean]		
Car driver		
Car pooling	0.32	3.21
Bicycle		
Slow two-wheelers		
Train		
Bus		
Working locations		
Schiphol Centre [boolean]		
Car driver	-0.13	-2.62
Car pooling		
Bicycle		
Slow two-wheelers		
Train		
Bus	1.36	13.40

Parameter [unit]	Value	Rob. t-stat.
Other individual characteristics		
Gender [boolean]		
Car driver	0.32	2.98
Car pooling		
Bicycle	-0.73	-4.45
Slow two-wheelers	-0.71	-3.67
Train	0.26	2.24
Bus	0.42	3.11
Age <18-24 years[5] [boolean]		
Car driver		
Car pooling		
Bicycle		
Slow two-wheelers		
Train	1.61	13.11
Bus	2.01	12.27
Age 25-39 years[5] [boolean]		
Car driver		
Car pooling		
Bicycle		
Slow two-wheelers		
Train		
Bus	0.58	5.23
Age >55 years[5] [boolean]		
Car driver	-0.16	-2.91
Car pooling		
Bicycle	0.37	3.34
Slow two-wheelers	0.50	3.52
Train		
Bus		
Summary statistics		
McFadden R^2		0.482
Adjusted McFadden R^2		0.480

Note: The parameters reported in the table were statistically significant on a 99% confidence level. When marked by an asterisk (*) the parameters was found only statistically significant on a 95% confidence level

5.2.1. INTERPRETATION OF RESULTS

TRAVEL TIME, COSTS & ACCESSIBILITY

Travel time and costs have a negative parameter sign, as also observed for passengers and in literature (Alkaabi, 2016; Habib, 2012; Tsamboulas et al., 2012). Also, the sign for all distances towards facilities is negative, implying that the further someone lives from a highway onramp or a(n) (intercity) train station, the higher the disutility. The latter is also observed in Limtanakool et al. (2006). The ratio between the travel cost parameters is in line with expectations. Usually, the bus users have a relatively low income compared to car and train users and therefore have a higher price elasticity, contrasting the findings of Tsamboulas et al. (2012). They studied the access mode choice of Athens airport personnel employing a stated preference study. Nonetheless, they mentioned that the airport bus is free of charge explaining their low price elasticity for bus users. For the travel time parameter, the same pattern as for passengers is observed, with alternatives without travel cost parameter

[4] Working 2-4 days at Schiphol Airport being the reference group
[5] Age 40-54 years old being the reference group

generally having a higher disutility for an increase in travel time. Potentially, some of the costs for a certain alternative are represented in the travel time parameter. Moreover, the effect of travel time reliability was not found to be significant, as also found in Sweet & Chen (2011). In contrast to passengers, personnel originates relatively close to Schiphol Airport, resulting in more reliable travel times.

Type of Working Hours

Personnel traveling during typical commuting hours use private car options less, while using the train more often. The presence of traffic congestion during peak hours potentially explains this. Moreover, aviation workers are less inclined to use buses and carpooling. This group originates further from Schiphol Airport and has irregular hours, making these two alternatives less attractive. Current literature on access mode choice of personnel commuting to airport never consider different working hours as an explanatory variable, but stresses the potential complexity associated with it. For commuting in general, Habib (2012) found that access mode choice is indeed affected by the type of working hours.

Working Onsite

Table 14 shows that whether or not someone works from home at least one day in the week and how often someone works onsite has little influence on the access mode choice. Only when working 5 or more days at Schiphol Airport positively affects the chance of choosing carpooling. It is probable that carpooling is used on a daily basis, as it comes with agreements between the driver and its passenger(s). None of the literature documented the importance of working onsite on airport access mode choice. However, Alkaabi (2016) found that full-time workers have a preference for the use of cars and public transport, in contrast to part-time workers.

Working Location

The working location influences the preferred access mode choice. When working at Schiphol Centrum, driving a car is less probable, while bus usage is higher. There are large walking distances between the parking sites for personnel at Schiphol Centrum, possibly explaining why this alternative is not favoured. Also, the public transport solutions at Schiphol Centrum are characterised by a high frequency and a low travel time, making it unnecessary to use the car.

Other Individual Characteristics

It became apparent that women are less likely to use slower modes of transport (bicycle and slow motorised two-wheelers) and are more likely to use public transport or drive a car. Alkaabi (2016) found a preference of women towards public transport. Moreover, an age bias is observed for access mode choice. Employees between 18 and 24 are more inclined to use public transport, as car ownership among this age group is relatively low (CBS, 2021). Furthermore, bus usage is more probable for the 25-39 age group. In contrast, employees aged older than 55 are more likely to use active modes, such as the bicycle. This group's travel distance is, on average, 15.3% shorter compared to the reference age group, potentially explaining why using an active mode is a viable alternative. Also, Alkaabi (2016) found that car usage decreases with age.

5.2.2. Validation of Explanatory Power

The previous section introduced the parameter (sign) interpretation. In the remainder of this section, the results of the other three validation approaches are presented, namely the value of time savings, the goodness-of-fit and the market shares.

Value of Time Savings

The values of time savings obtained from the global model are compared to the values obtained in KiM (2023), as presented in Table 15. The value of time savings refers to how much euro an employee is willing to pay to reduce the travel time by one hour for a certain access mode. Only a comparison could be made for alternatives, that include a travel cost component, namely car driver, train and bus.

TABLE 15: VALUE OF TIME SAVINGS COMPARISON FOR PERSONNEL

Access Mode	Global MNL [€/h]	KiM (2023) [€/h]
Car	8.9	10.78
Train	11.1	12.05
Bus	2.8	7.62
Bicycle	-	10.17

The table illustrates that the found values of time savings are lower than in KiM (2023), however the same ranking between the alternatives is observed. The estimated value of time savings for bus travel (2.8 €/h) is notably lower compared to the value reported in KiM (2023). Potentially, travel costs are paid by the employer, hence a low price elasticity is expected. Indeed, 11.4% of the respondents using the bus mention that they use a public transport card made available by the employer. However, for train users, this is 24.2%, while not having a substantially lower value of time savings. It is striking that bus users have a significantly shorter average travel distance (17.6 kilometres) compared to train users (47.7 kilometres) and car drivers (40.6 kilometres). Shires & De Jong (2009) found in a meta-analysis conducted among literature on values of time savings throughout the European Union that the value of time savings is indeed lower for shorter travel distances. Their findings correspond to other literature (Heywood & Lee, 2016; Wardman, 2022).

GOODNESS-OF-FIT

The model has a high adjusted McFadden R^2 of 0.480, indicating an excellent fit (Hensher et al., 2015, Chapter 7; McFadden, 1975). Also, the adjusted McFadden R^2 of the model is relatively stable. When estimating the model for 40% and 20% of the data, adjusted McFadden R^2's of 0.478 and 0.495 are obtained, respectively.

MARKET SHARES

The total market shares are estimated using the validation dataset. The results are presented in Figure 23.

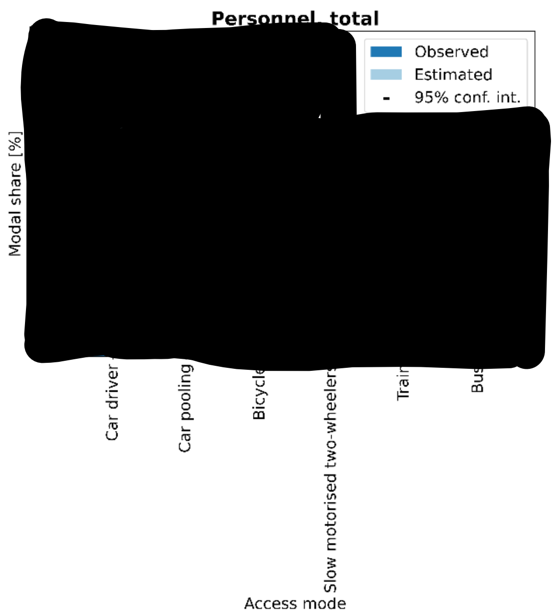


FIGURE 23: PERSONNEL TOTAL MARKET SHARE

Due to the differences in workforce and respondents in the dataset and their corresponding preferences, it is expected that the predictive power is much higher for the location with the most respondents, Schiphol Centrum, compared to the working locations outside Schiphol Centrum. This comparison is visualised in Figure 24. For the two specific market segments 1,895 and 871 responses remained available in the validation dataset, respectively.

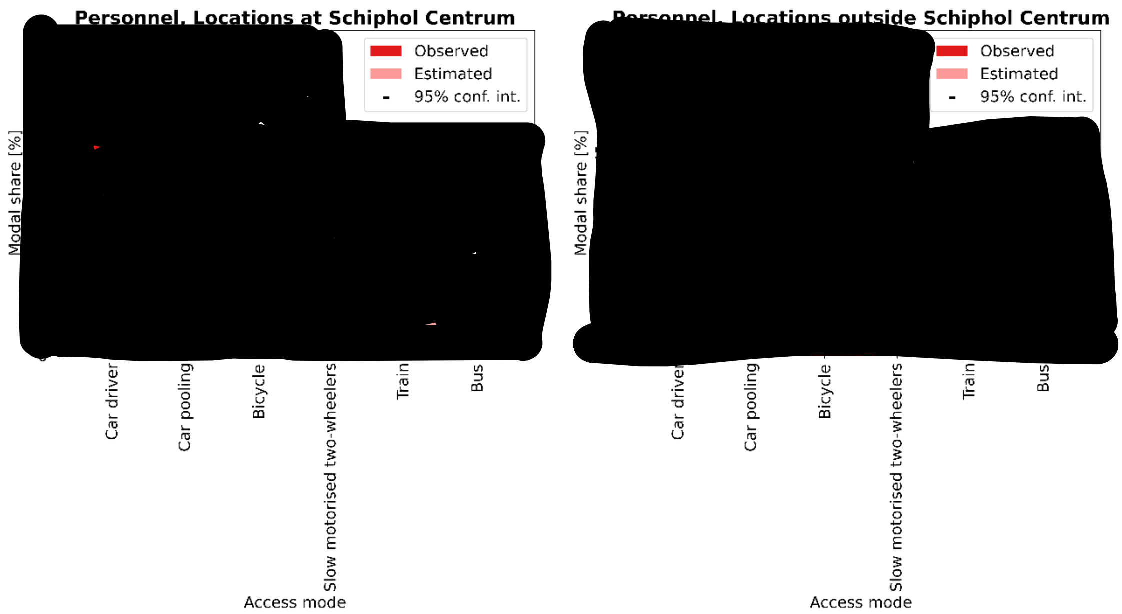


FIGURE 24: SPECIFIC PERSONNEL MARKET SHARES FOR LEFT) PERSONNEL WORKING AT SCHIPHOL CENTRUM; AND RIGHT) PERSONNEL WORKING OUTSIDE SCHIPHOL CENTRUM

The figure illustrates that the model corresponds well for personnel working at Schiphol Centrum, but less for the working locations outside of Schiphol Centrum. Especially, the high share of car drivers cannot be estimated accurately. Nonetheless, the proportions in the modal share are well-captured.

5.2.3. SYNTHESIS

This section introduced the model estimation for personnel. For personnel a wide variety of variables explain access mode choice, however the number of days working onsite and whether or not someone works from home does not contribute substantially to access mode choice. Again, the model fit is excellent and the model estimates modal shares well on a total and segmented level. A substantial difference in access mode choice is observed between working at Schiphol Centrum compared to elsewhere. Although the model can capture modal share proportions, it is not sufficiently accurate for estimating absolute personnel volumes (for specific segments).

6. MODEL APPLICATION

This section shows the estimation of the modal share in a base scenario and in future scenarios, corresponding to the fifth and sixth step of the methodology (Section 4.4 and 4.5, respectively). In every future scenario, a donut diagram is used for comparison purposes, in which the inner circle represents the current modal share (base scenario) and the outer circle represents the modal share under future conditions (future scenario).

6.1. BASE SCENARIO: 2023

The modal share estimation of the model in the base scenario (2023) for the population of passengers is presented in the inner ring of Figure 25. With some responses excluded from the dataset (see Section 3.2.1), this modal share provides the demand distribution for 15.7 million departing passengers, which is 80.0% of the total departing passengers.

The inner ring of Figure 28 shows the modal share for personnel in the base scenario (2017). Due to the exclusion of 5.9% of the responses, the modal share is more representative for the whole population compared to the passengers, representing 61,873 employees, 92.5% of the total workforce.

6.2. SCENARIO 1: 10% PARKING FARE INCREASE AT P3

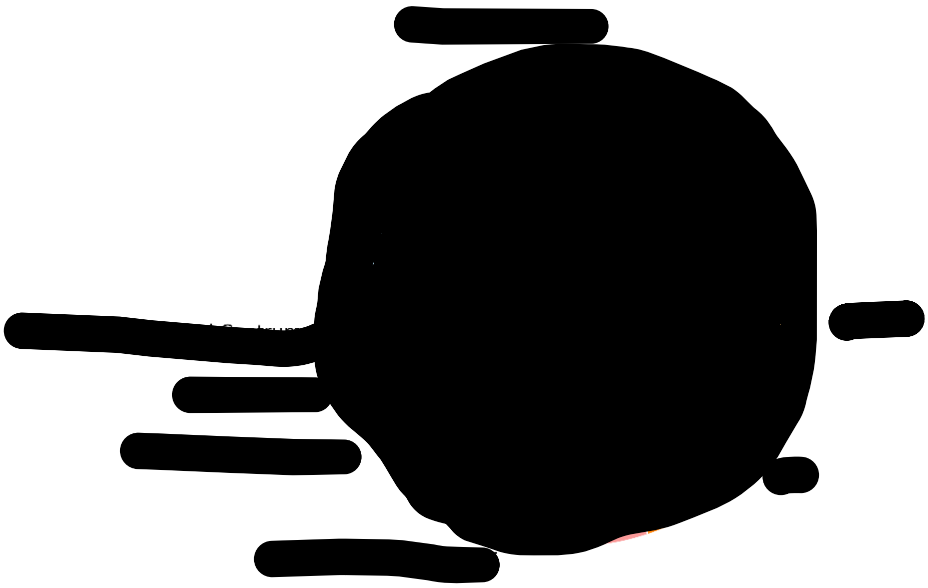


FIGURE 25: MODAL SHARE FOR A 10% PARKING FARE INCREASE AT P3

The outer circle of Figure 25 shows the modal share when implementing a 10% increase in the parking fares at P3. As expected, parking at P3 becomes less attractive, hence a decrease of 5.5% in the use of this parking facility. At first glance, this difference seems minimal, however it corresponds to a decrease in the usage of P3 by 44,000 passengers. So, further inflated parking fares contribute substantially to the goals of Schiphol Airport in having fewer car movements on the surrounding road network.

The decrease is relatively high compared to the rule of thumb for parking in the Netherlands in general presented in KiM (2018), in which a decrease in usage of 3% is expected after a 10% fare increase. Nonetheless, they mentioned that the decrease in usage is highly affected by the purpose of parking, the timing, duration of parking and the location. Also, when parking at Schiphol, costs are substantially higher compared to conventional parking in, for example, a city centre. As a result, a higher price elasticity is expected.

Despite a slight increase in the use of the parking facilities at Schiphol Centum is observed, most passengers switch to public transport or being brought by car, drop-off. Parking fares for Schiphol Centrum remain, for a longer duration of stay, still higher than the parking rates for P3, making it not always a viable option for passengers on a stricter budget.

6.3. SCENARIO 2: PASSENGER PROJECTION FOR 2040

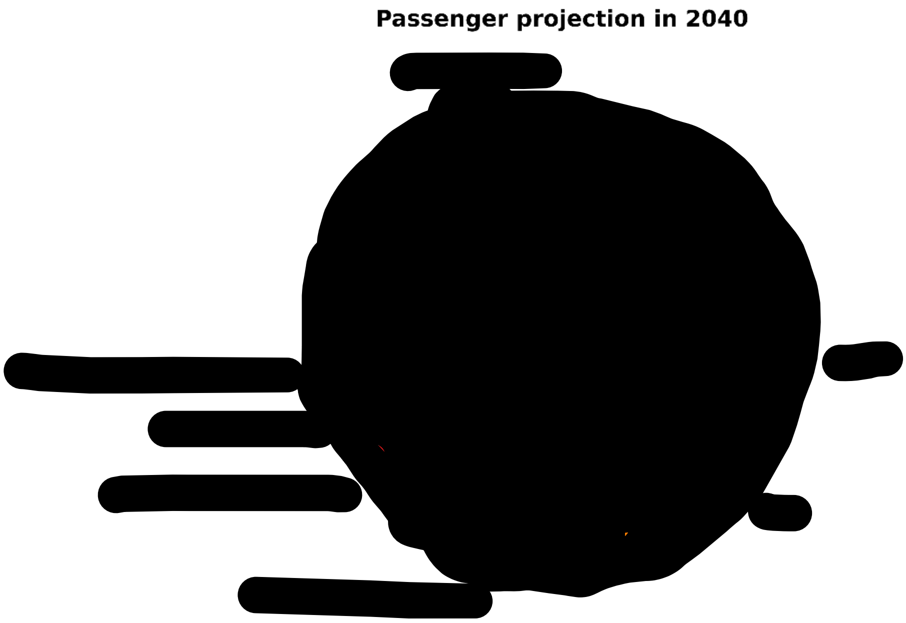


FIGURE 26: MODAL SHARE FOR PASSENGER PROJECTION FOR 2040

Figure 26 shows the modal share when extrapolating passenger volumes to 2040. In 2040 it is expected that the share of business travellers will be less, while especially the share of the international – leisure segment will increase substantially. International – leisure travellers prefer the use of taxis, rental cars and public transport as access mode, hence their modal share increases by 3.6%, 1.3% and 1.1%, respectively. With a decrease in the share of resident travellers, parking the car and being brought by car, has a decrease by 9.6% and 2.0%, respectively, in the modal share. Nonetheless, due to increased passenger volumes in 2040, the absolute volumes of the latter two modes are still increasing, as illustrated in Figure 27. These figures illustrate that a change in passenger profile leads to a substantially different modal share in the future, underlining the importance for Schiphol Airport to monitor and manage the transportation of future passenger volumes.

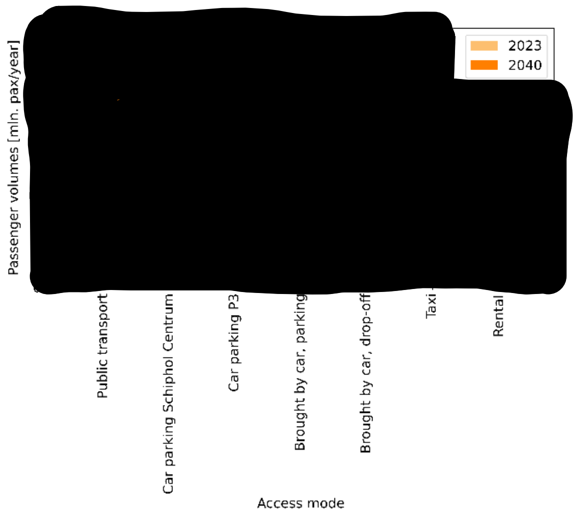


FIGURE 27: ACCESS MODE CHOICE FOR ABSOLUTE PASSENGER VOLUMES IN 2023 AND 2040

6.4. SCENARIO 3: PERSONNEL PROJECTION FOR 2040

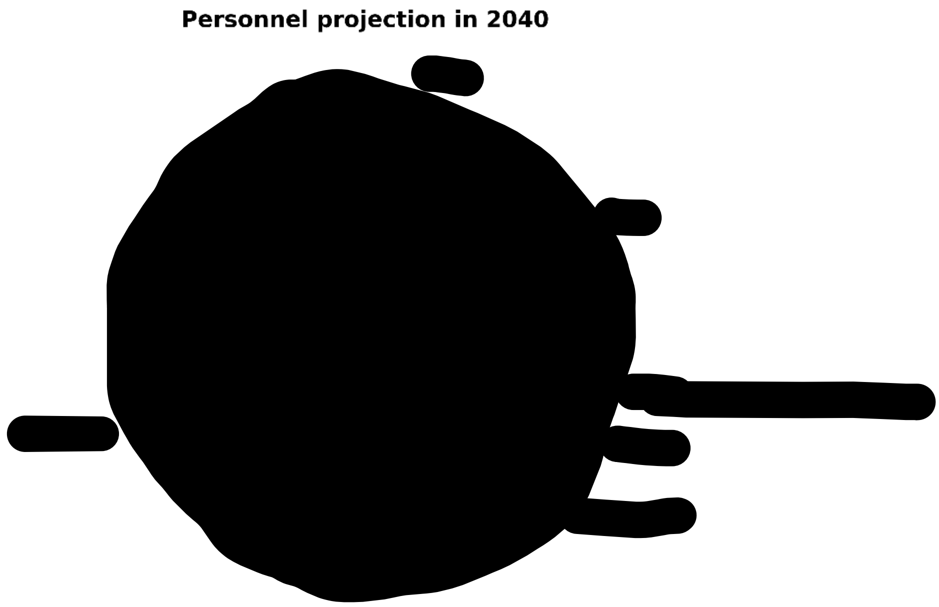


FIGURE 28: MODAL SHARE FOR PERSONNEL PROJECTION FOR 2040

Figure 28 shows that with the expansion of the workforce at the Schiphol areal, barely any change in modal share is expected. The reason for this may be that the expansion of the workforce is relatively evenly distributed between locations at Schiphol Centrum and locations outside (8,961 and 7,653 jobs, respectively). The usage of bicycles is relatively high for Schiphol Oost and Technisch Areaal Oost and as a result, a small increase in the modal share of bicycles (+3.3%) and slow motorised two-wheelers (1.4%) is expected for 2040. In contrast, the modal share of buses reduces slightly by 2.1%.

7. DISCUSSION

This study evaluated variables explaining access mode choice for passengers and personnel travelling to Schiphol Airport. This section discusses the limitations of the study, specifically in its data and methods used. Moreover, some generalisations with respect to the study area are made.

7.1. LIMITATIONS IN DATA AND METHODS

7.1.1. LIMITATIONS IN DATA

EXCLUSION OF RESPONSES

In this study, two large questionnaire datasets are used with 54,588 and 15,476 responses for passengers and personnel, respectively. Many responses had to be deleted due to incompleteness or errors, making it impossible to reconstruct the trip for both the chosen and non-chosen alternatives. This resulted in a less representative sample and consequently a less representative weighted sample or population when applying the model in the current state and in future scenarios. This is particularly a problem for passengers, as 20% of their data had to be discarded. Nonetheless, the number of remaining responses is still larger than observed in all literature presented in Table 3.

MISSING EXPLANATORY VARIABLES

Both datasets were very rich in the number of explanatory variables included. However, various explanatory variables of which the relevance in access mode choice is proven via literature were not included in the datasets, as the datasets were not specifically designed for this study. This includes important variables such as the number of luggage items, access group size and income. As a result, the currently included explanatory variables might represent missing explanatory variables to a certain extent. This behaviour was already observed for alternatives for which no travel costs were included. For those alternatives, the travel time elasticities were more negative, possibly indicating that the travel time parameter incorporates the travel costs of these alternatives to a certain extent. Therefore, some of the elasticities might be overestimated. Moreover, no questions regarding the availability of alternatives were included, whereas literature indicated the importance of this on access mode choice. Thus, it might be that an alternative is considered in the choice set of a respondent, whereas the alternative was not available for that individual.

Finally, both datasets included only little information about the trip and as a result, the trip is reconstructed using Mobility Spectrum for both the chosen alternative and the non-chosen alternatives. However, it is possible that the reconstructed fastest route does not correspond to the route actually used by a passenger or employee. Environmental and route characteristics, such as public transport frequency, comfort level, and land use, might lead individuals to opt for a different, slightly longer route (e.g. Bovy & Hoogendoorn-Lanser (2005), Eltved et al. (2018) and Prato et al. (2018)), an thus price and time elasticities might be underestimated. The dataset for personnel included ranges for travel time and distance (e.g. travel time between 30-44 minutes), allowing for verification of these characteristics. However, the data required for this verification was not available for passengers.

7.1.2. LIMITATIONS IN METHODS

DEALING WITH HETEROGENEITY

In this study, the MNL model is employed, in which is accounted for heterogeneity in preferences between subgroups. This is done via two approaches, namely by including dummy variables for subgroups and estimating separate models per subgroup. Besides, a separate model parameter is included for every mode alternative, allowing for variation between the alternatives. Often literature does not allow for that much variation, for example, by only including one overarching travel costs parameter, instead of one per alternative (Hess & Polak, 2006; Jou et al., 2011; Sobieniak et al., 1979) However, heterogeneity in preferences within subgroups is not included in the MNL model. There exist models that are specifically designed to account for this type of heterogeneity, namely MMNL models. Allowing for this type of heterogeneity allows for variation in the elasticities for selected variables. For example, price elasticities are often not uniformly distributed among travellers as a result of income. Allowing for this variation could greatly improve the model fit, while also improving information about the variability of the elasticity. As a result, it could be worth using an MMNL model in a future study.

Utility Function Specification

The design of the utility function is not trivial, hence the specification of this function is a laborious practice. In this study, a structured approach was used in which it was tried to evaluate the full solution space. The bottom up and top down approach allowed for this. The adjusted McFadden R^2, the goodness-of-fit statistic, guided on the utility specifications and when to stop considering more specifications. However, numerous utility specifications remain unexplored, some of which might potentially yield better fits. This includes different subsets of explanatory variables or alternative model structures that could be identified using other utility specification algorithms such as the one by Ortelli et al. (2021). Their algorithm translates the utility specification into a multi-objective combinatorial optimisation problem and uses a variant of the variable neighbourhood search algorithm to generate sets of promising model specifications. Also, further transformations of variables could provide better results. The natural log transformation is often yielded, as it represents that the utility effect of, for example, increasing the travel time by one minute at high travel times has a lower effect than an one minute increase at low travel times (Koppelman & Bhat, 2006, Chapter 5). However, in this study, employing such transformations for travel costs or time resulted in a decreased model performance.

Validation of Discrete Choice Models

The validation of discrete choice models is not trivial and many studies use different (combinations of) approaches (Parady et al., 2021). This study tried to get a clear picture of the model's validity by employing four validation steps. One approach was to compare the values of time savings of KiM (2023) and the ones found in this study. However, differences in approaches used in both studies complicated the comparison. This study revealed the price someone was willing to pay to reduce its travel time, whereas KiM (2023) showed the intention in the willingness to pay (Bernardi et al., 2018). Literature indicates that there exists differences between the observed value of time savings of a revealed preference study compared to a stated preference study, and therefore a comparison has to be made with care. As a result, the ratios between the values of time savings of the different alternatives have been used mostly for validation purposes and not the exact values.

7.2. Generalisations considering the Study Area

The focus of this study was on Schiphol Airport, the 4th biggest airport in Europe when it comes to passenger volumes. The results and their interpretation are difficult to generalise, as access mode choice is highly airport context-specific, due to the access alternatives available. Also, airport size and throughput play a role in explaining access mode choice (Gupta et al., 2008). Future research in other airport contexts may shed light on the differences between airport contexts.

8. CONCLUSIONS & RECOMMENDATIONS

This section provides the conclusions per research question and an overarching conclusion to the research aim. Thereafter, practical recommendations and recommendations for future research are given.

8.1. CONCLUSION

Q1 "Which explanatory variables play a role in airport access mode choice to Schiphol Airport according to literature and for which of these variables is data available for model parameter value estimation?"

Literature indicates various variables explanatory for airport access mode choice for passengers and personnel, illustrated in Table 3. Following data limitations, only the following list of explanatory variables is included for the remainder of the analysis. Whether the variable applies to passengers or personnel is indicated with an asterisk (*) and a circumflex (^), respectively.

Trip variables
- Travel time * ^
- Travel costs * ^
- Parking costs *
- Travel time reliability * ^

Origin variables
- Distance to highway onramp * ^
- Distance to train station * ^
- Distance to IC train station * ^

Individual characteristics variables
- Trip purpose *
- Duration of stay *
- Residence *
- Flight destination *
- Night flight *
- Gender * ^
- Age * ^
- Working hours ^
- Working location ^
- Working from home ^
- Days working on-site ^

Q2 "How (well) do the estimated parameters of the discrete choice model explain access mode choice and what is their coherence and importance?"

The estimated discrete choice models illustrated that various explanatory variables affect access mode choice for passengers and personnel. Most of the parameter values in the estimated models show plausible signs and proportions and the values of time savings of the models compared to the ones found in KiM (2023). Moreover, both models demonstrated a good fit following the adjusted McFadden R^2 and when estimating market shares for an internal validation dataset, the models are well-capable in capturing proportions in modal share for all passengers and personnel and specific segments. Nonetheless, they are not accurate enough to estimate exact volumes.

Q3 "What is the model share when applying the estimated access mode choice model on the whole population of passengers and personnel in a base scenario?"

Acknowledging the validity of the estimated models, the models are used to estimate the modal share for the whole population of departing passengers and personnel, presented in the inner ring of Figure 25 and Figure 28, respectively.

Q4 "How does the modal share change in future scenarios, compared to the base scenario?"

When the parking fares for P3 are increased by 10%, a decrease of 5.5% in the usage of this parking facility is expected. As a consequence, a surge in the modal share of public transport and being brought by car, drop-off can be expected. Moreover, when projecting the trends for residence and their trip purpose in 2040, an increase in the modal share of taxis, rental cars and public transport is expected. In contrast, the use of car parking and being brought by car is expected to decrease. Besides that, when projecting personnel growth as a result of real estate development for 2040, barely any change in the modal share is expected. Only a slight increase in the modal share of bicycles and slow motorised two-wheelers is expected, while buses are expected to be chosen slightly less often.

Aim *"To explain access mode choice of passengers and personnel to Schiphol Airport by estimating a discrete choice model and to apply the model to evaluate the effect of future scenarios on the modal share"*

A discrete choice model has been estimated to explain the access mode choice of passengers and personnel travelling to Schiphol Airport. The models perform well in capturing proportions in the modal share; not only for the modal share for all passengers and personnel, but also for more specific segments. Nonetheless, the models' accuracy is insufficient for usage of the models to predict absolute volumes per access mode. Using this knowledge, the models are applied to the passenger and personnel population, to obtain modal shares. Also, the models are applied to evaluate the modal share in future scenarios, a 10% parking fare increase at P3, projecting passenger purpose and residence composition for 2040, on the modal share under these circumstances and projecting personnel growth for 2040.

8.2. Recommendations

8.2.1. Practical Recommendations for Schiphol Airport

The estimated models provide an understanding of why passengers and personnel choose a certain access mode and give an idea of the magnitude and direction of a mode shift under future scenarios. Using this knowledge, Schiphol Airport can identify measures that contribute further to their goals stated in Goudappel (2023a), such as decreasing the number of non-fossil fuelled vehicle trips. As the estimated models perform well in explaining access mode choice proportions, it is also recommended to integrate the models within the STDM. This allows for the evaluation of the consequences of a modal shift on the traffic volumes on a road segment level around Schiphol Airport and thus allows for the evaluation of bottlenecks in the current road infrastructure.

To improve the ability of the model to estimate absolute volumes, it is recommended to calibrate the ASCs on observed passenger and personnel volumes per mode alternative, instead of estimating it on sample datasets. The ASCs capture the systematic difference in utility of alternatives that are not captured by the explanatory variables and they are specifically estimated for the samples. By calibration of the ASCs on observations, a more accurate modal share can be obtained. Other model parameters cannot be calibrated based on observed data, as most explanatory variables are unknown for the full population. The estimated parameter values based on the sample dataset are thus recommended to apply the full population, as the elasticities are expected to be the same for the sample dataset and the full population.

Currently, heterogeneity between subgroups is included for some segments (Table 9). To improve the ability to estimate absolute volumes for specific segments, it is recommended to allow for heterogeneity between subgroups for other segments as well. Especially, on segments that are of interest to Schiphol Airport, such as the differentiation between different quarters of the year for passengers. This study included two approaches for dealing with heterogeneity. It is recommended to include more dummy variables, as this is the most convenient way to deal with this heterogeneity, while maintaining a good performance.

It is advised to Schiphol Airport to undertake a stated preference study, to allow for the evaluation of the response of passengers and/or personnel to new measures. Due to the controlled nature of stated preference datasets, they allow for the exploration of the response to alternatives or attributes that are currently not in place or not within the limits that are currently observed (Hensher, 1994). The conditions of the revealed preference dataset should be taken into account when designing the stated preference questionnaire (Hensher & Bradley, 1993). For example, similar definitions of explanatory variables should be employed. Then, stated and revealed preference datasets can be combined in one analysis as Jou et al. (2011) also employed when analysing the effect of introducing a new mass rapid transit system between the airport and important traffic hubs in Taiwan. Via this way, the modal share can be calculated in a wider diversity in future scenarios. An example of this is the inclusion of parking costs for the brought by car, drop-off option, but also extending the parking fares outside the currently observed range.

8.2.2. RECOMMENDATIONS FOR FUTURE RESEARCH

Various models exist within the discrete choice model family, of which the MNL is employed in this study. However, an MMNL model has significant advantages over the MNL model, as it allows for random taste variation between individuals, resulting in a more reliable and robust model. This was illustrated by Jou et al. (2011), which obtained an adjusted McFadden R^2 value of 0.83. Due to the large size of the datasets available in this study, the computation time of an MMNL model became a serious issue. Nonetheless, it could be worth investing in the specification of an MMNL model that does not come with outrageous computation times in a future study. For example, by using segmented models and investigating if the model indeed has an improved fit and thus being more accurate in explaining access mode choice of passengers and personnel.

BIBLIOGRAPHY

Abubakar, U., Nasiru, M. A., & Abubakar, F. U. (2020). The Regulating Influence of Rehabilitation and Awareness Campaign on the Relationships between Transportation, Stigma, Quality of Health and Health-seeking Behavior among Obstetric Fistula Patients in North-west Nigeria: A Pilot Study. *International Journal of Research and Scientific Innovation (IJRSI) |*, *VII*. www.rsisinternational.org

Agrawal, R., & Srikant, R. (1994). Fast Algorithms for Mining Association Rules. *VLDB '94: Proceedings of the 20th International Conference on Very Large Data Bases*, 487–499.

Ali, I. A., Rouhana, F., Eddine, R. Z., & Al Zoer, S. (2019). Estimating Travel Mode Choices of NDU Students Using Multinomial Logit Model. *2019 4th International Conference on Advances in Computational Tools for Engineering Applications, ACTEA 2019*. https://doi.org/10.1109/ACTEA.2019.8851118

Alkaabi, K. A. (2016). Modeling travel choice behavior of airport employees for commuting to work at Dubai International Airport, UAE. *Sustainable Development and Planning VIII*, *1*, 577–589. https://doi.org/10.2495/sdp160481

Aloulou, F. (2018). The Application of Discrete Choice Models in Transport. In *Statistics - Growing Data Sets and Growing Demand for Statistics*. InTech. https://doi.org/10.5772/intechopen.74955

Ameen, N., & Kamga, C. (2013). Forecast of airport ground access mode choice with the incremental logit model. *Transportation Research Record*, *2336*, 97–104. https://doi.org/10.3141/2336-12

Anderson, M. K., Nielsen, O. A., & Prato, C. G. (2017). Multimodal route choice models of public transport passengers in the Greater Copenhagen Area. *EURO Journal on Transportation and Logistics*, *6*(3), 221–245. https://doi.org/10.1007/S13676-014-0063-3

ANWB. (n.d.). *Verkeersinfo, dagelijks drukke trajecten, spits Nederland*. Retrieved 16 April 2024, from https://www.anwb.nl/verkeer/nederland/verkeersinformatie/dagelijkse-drukke-trajecten

Autoweek. (n.d.). *Verbruiksmonitor | Verbruik auto in de praktijk*. Retrieved 5 March 2024, from https://www.autoweek.nl/verbruiksmonitor/?referrer=https%3A%2F%2Fwww.google.com%2F&brandstof=benzine

Bayaga, A. (2010). Multinomial Logistic Regression: Usage and Application in Risk Analysis. *Journal of Applied Quantative Methods*, *5*(2).

Ben-Akiva, M., & Lerman, S. R. (1985). *Discrete Choice Analysis: Theory and Application to Travel Demand*. Massachusetts Institute of Technology. https://books.google.nl/books?id=oLC6ZYPs9UoC&pg=PA1&source=gbs_toc_r&cad=2#v=onepage&q&f=false

Bernardi, S., Geurs, K., & Puello, L. L. P. (2018). Modelling route choice of Dutch cyclists using smartphone data. *Journal of Transport and Land Use*, *11*(1), 883–900. https://doi.org/10.5198/JTLU.2018.1143

Bierlaire, M. (2009). *Estimation of discrete choice models with BIOGEME 1.8*.

BNR, & ANWB. (2014, April 23). *Autobezitter heeft vaak geen benul van autokosten*. Onderzoek Door GfK i.o.v. ANWB En BNR. https://www.bnr.nl/nieuws/mobiliteit/10070364/autobezitter-heeft-vaak-geen-benul-van-autokosten

Borboudakis, G. (2019). Forward-Backward Selection with Early Dropping. *Journal of Machine Learning Research*, *20*, 1–39. http://jmlr.org/papers/v20/17-334.html.

Bovy, P. H. L., & Hoogendoorn-Lanser, S. (2005). Modelling route choice behaviour in multi-modal transport networks. *Transportaton*, *32*, 341–368.

CBS. (2019, July 15). *Werknemers Schiphol, 2017*. Centraal Bureau Voor de Statistiek. https://www.cbs.nl/nl-nl/maatwerk/2019/29/werknemers-schiphol-2017

CBS. (2021, April 11). *Autobezit personen naar leeftijd, 2020 en 2016*. Centraal Bureau Voor de Statistiek. https://www.cbs.nl/nl-nl/maatwerk/2021/14/autobezit-personen-naar-leeftijd-2020-en-2016

CBS. (2023a). *Pompprijzen motorbrandstoffen; locatie tankstation, brandstofsoort*. Centraal Bureau Voor de Statistiek. https://www.cbs.nl/nl-nl/cijfers/detail/81567NED

CBS. (2023b). *Wijk- en buurtkaart 2023*. Centraal Bureau Voor de Statistiek.

CBS. (2023c, August 30). *Buurt, wijk en gemeente 2023 voor postcode huisnummer*. Centraal Bureau Voor de Statistiek. https://www.cbs.nl/nl-nl/maatwerk/2023/35/buurt-wijk-en-gemeente-2023-voor-postcode-huisnummer

CBS. (2023d, November 6). *Nabijheid voorzieningen; afstand locatie, wijk- en buurtcijfers 2022*. Centraal Bureau Voor de Statistiek. https://www.cbs.nl/nl-nl/cijfers/detail/85560NED

Changpetch, P., & Lin, D. K. J. (2013). Selection of multinomial logit models via association rules analysis. *Wiley Interdisciplinary Reviews: Computational Statistics*, *5*(1), 68–77. https://doi.org/10.1002/WICS.1242

Choo, S., You, S. (Iris), & Lee, H. (2013). Exploring characteristics of airport access mode choice: a case study of Korea. *Transportation Planning and Technology*, *36*(4), 335–351. https://doi.org/10.1080/03081060.2013.798484

Chowdhury, M., & Turin, T. C. (2020). Variable selection strategies and its importance in clinical prediction modelling. *Fam Med Com Health*, *8*, 262. https://doi.org/10.1136/fmch-2019-000262

Colovic, A., Pilone, S. G., Kukić, K., Kalić, M., Dožić, S., Babić, D., & Ottomanelli, M. (2022). Airport Access Mode Choice: Analysis of Passengers' Behavior in European Countries. *Sustainability*, *14*(15). https://doi.org/10.3390/su14159267

de Groot, N. (2023, April 21). *Parkeren bij het vliegveld duurder: gemiddeld 75 euro voor een week*. AD. https://www.ad.nl/binnenland/parkeren-bij-het-vliegveld-duurder-gemiddeld-75-euro-voor-een-week~a5c3d4ac/?referrer=https%3A%2F%2Fwww.google.com%2F

De Neufville, R., & Odoni, A. R. (2013). *Airport Systems: Planning, Design, and Management* (2nd ed.). McGraw-Hill.

Dissanayake, D., & Jehanfo, S. (2009). Modelling surface access mode choice of air passengers. *Proceedings of The Institution of Civil Engineers-Transport - PROC INST CIVIL ENG-TRANSPORT*, *162*, 87–95. https://doi.org/10.1680/tran.2009.162.2.87

Dumbliauskas, V., Grigonis, V., & Barauskas, A. (2017). Application of Google-based Data for Travel Time Analysis: Kaunas City Case Study. *Promet - Traffic&Transportation*, *29*(6), 613–621. https://doi.org/10.7307/PTT.V29I6.2369

Ellis, R. H., Bennett, J. C., & Rassam, P. R. (1974). Approaches for Improving Airport Access. *Journal of Transportation Engineering*, *100*(TE3), 661–673.

Eltved, M., Nielsen, O. A., & Rasmussen, T. K. (2018). *The Influence of Frequency on Route Choice in Mixed Schedule- and Frequency-based Public Transport Systems - The Case of the Greater Copenhagen Area* (Vol.

28, p. 2024). https://orbit.dtu.dk/en/publications/the-influence-of-frequency-on-route-choice-in-mixed-schedule-and-

Fosgerau, M., & Bierlaire, M. (2007). A practical test for the choice of mixing distribution in discrete choice models. *Transportation Research Part B: Methodological*, *41*(7), 784–794. https://doi.org/10.1016/J.TRB.2007.01.002

Gardiner, J., Ison, S., & Humphreys, I. (2005). Factors influencing cargo airlines' choice of airport: An international survey. *Journal of Air Transport Management*, *11*(6), 393–399. https://doi.org/10.1016/J.JAIRTRAMAN.2005.05.004

Gazelle. (n.d.). *Wat kost een elektrische fiets of speed pedelec?* Retrieved 14 May 2024, from https://www.gazelle.nl/advies/elektrische-fietsen/kosten

Glerum, A., Atasoy, B., & Bierlaire, M. (2014). Using semi-open questions to integrate perceptions in choice models. *Journal of Choice Modelling*, *10*(1), 11–33. https://doi.org/10.1016/J.JOCM.2013.12.001

Golshani, N., Shabanpour, R., Mahmoudifard, S. M., Derrible, S., & Mohammadian, A. (2018). Modeling travel mode and timing decisions: Comparison of artificial neural networks and copula-based joint model. *Travel Behaviour and Society*, *10*, 21–32. https://doi.org/10.1016/J.TBS.2017.09.003

Google. (n.d.). *Distance Matrix API request and response*. Retrieved 25 April 2024, from https://developers.google.com/maps/documentation/distance-matrix/distance-matrix

Goudappel. (2023a). *Deelrapport 3a - Mobiliteit*.

Goudappel. (2023b). *Schiphol Model demo (internal document)*.

Goudappel. (2024). *Beheersmaatregelen Drop Off Zone (confidential document)*.

Gunay, G., & Gokasar, I. (2021). Market segmentation analysis for airport access mode choice modeling with mixed logit. *Journal of Air Transport Management*, *91*, 102001. https://doi.org/10.1016/J.JAIRTRAMAN.2020.102001

Gupta, S., Vovsha, P., & Donnelly, R. (2008). Air Passenger Preferences for Choice of Airport and Ground Access Mode in the New York City Metropolitan Region. *Transportation Research Record*, *2042*(1), 3–11. https://doi.org/10.3141/2042-01

Habib, K. M. N. (2012). Modeling commuting mode choice jointly with work start time and work duration. *Transportation Research Part A: Policy and Practice*, *46*(1), 33–47. https://doi.org/10.1016/J.TRA.2011.09.012

Hagens, J., Kruger, M., & Copping, M. (2017). *Ruimte voor werken in de MRA van morgen: 2017-2030*. www.bureaubuiten.nl

Hasnine, M. S., & Habib, K. N. (2018). What about the dynamics in daily travel mode choices? A dynamic discrete choice approach for tour-based mode choice modelling. *Transport Policy*, *71*, 70–80. https://doi.org/10.1016/J.TRANPOL.2018.07.011

Hensher, D. A. (1994). Stated preference analysis of travel choices: the state of practice. *Transportation*, *21*, 107–133.

Hensher, D. A. (2004). Identifying the Influence of Stated Choice Design Dimensionality on Willingness to Pay for Travel Time Savings. *Journal of Transport Economics and Policy*, *38*(3), 425–446.

Hensher, D. A., & Bradley, M. (1993). Using Stated Response Choice Data to Enrich Revealed Preference Discrete Choice Models. *Marketing Letters, a Journal of Research in Marketing*, *4*, 139–151.

Hensher, D. A., Rose, J. M., & Greene, W. H. (2015). Applied Choice Analysis. *Applied Choice Analysis*. https://doi.org/10.1017/CBO9781316136232

Hess, S., Bierlaire, M., & Polak, J. W. (2005). Estimation of value of travel-time savings using mixed logit models. *Transportation Research Part A: Policy and Practice*, *39*(2–3), 221–236. https://doi.org/10.1016/J.TRA.2004.09.007

Hess, S., & Palma, D. (2019). Apollo: A flexible, powerful and customisable freeware package for choice model estimation and application. *Journal of Choice Modelling*, *32*, 100170. https://doi.org/10.1016/J.JOCM.2019.100170

Hess, S., & Polak, J. W. (2005). Mixed logit modelling of airport choice in multi-airport regions. *Journal of Air Transport Management*, *11*(2), 59–68. https://doi.org/10.1016/J.JAIRTRAMAN.2004.09.001

Hess, S., & Polak, J. W. (2006). Airport, airline and access mode choice in the San Francisco Bay area. *Papers in Regional Science*, *85*(4), 543–567. https://doi.org/https://doi.org/10.1111/j.1435-5957.2006.00097.x

Heywood, C., & Lee, P. (2016). *Value of Time for Bus Passengers*.

Hofman, F. (2023). *Review Luchtvaartmodel AEOLUS*.

Hu, B., Palta, M., & Shao, J. (2006). PSEUDO-R 2 in logistic regression model. In *Statistica Sinica* (Vol. 16). https://www.researchgate.net/publication/228463155

Ishii, J., Jun, S., & Van Dender, K. (2009). Air travel choices in multi-airport markets. *Journal of Urban Economics*, *65*(2), 216–227. https://doi.org/10.1016/J.JUE.2008.12.001

Jehanfo, S., & Dissanayake, D. (2009). Modelling surface access mode choice of air passengers. *Proceedings of the Institution of Civil Engineers: Transport*, *162*(2), 87–95. https://doi.org/10.1680/tran.2009.162.2.87

Jou, R. C., Hensher, D. A., & Hsu, T. L. (2011). Airport ground access mode choice behavior after the introduction of a new mode: A case study of Taoyuan International Airport in Taiwan. *Transportation Research Part E: Logistics and Transportation Review*, *47*(3), 371–381. https://doi.org/10.1016/J.TRE.2010.11.008

Kager, R., & Harms, L. (2017). *Synergies from Improved Cycling-Transit Integration: Towards an integrated urban mobility system*. www.itf-oecd.org

Karunathilake, A. N., & Fernando, A. (2023). Identifying the key influencing factors for the growth of air cargo demand. *Journal of Global Operations and Strategic Sourcing*. https://doi.org/10.1108/JGOSS-06-2022-0072

Kieft, S. C., & Wilgenburg, J. (2009). 'Kookboek' Verkeerskundig Noordvleugelmodel VENOM. *Colloquium Vervoersplanologisch Speurwerk*.

KiM. (2018). *Sturen in parkeren*.

KiM. (2022a). *Het wijdverbreide autobezit in Nederland*.

KiM. (2022b). *Verklaringen voor de verschillen in autobezit bij Nederlandse huishoudens*.

KiM. (2023). *Values of Time, Reliability and Comfort in the Netherlands 2022 New values for passenger travel and freight transport*.

König, A., & Axhausen, K. W. (2002). The Reliability of the Transportation System and its Influence on the Choice Behaviour. *STRC 2002*. https://www.researchgate.net/publication/252089032

Koppelman, F. S., & Bhat, C. (2006). *A Self Instructing Course in Mode Choice Modeling: Multinomial and Nested Logit Models*.

KpVV. (2006). *De halte als voordeur van het openbaar vervoer*.

Lancsar, E., Fiebig, D. G., & Hole, A. R. (2017). This is a repository copy of Discrete Choice Experiments: A Guide to Model Specification, Estimation and Software. *PharmacoEconomics*, 697–716. https://doi.org/10.1007/s40273-017-0506-4

Li, Z., Hensher, D. A., & Ho, C. (2020). An empirical investigation of values of travel time savings from stated preference data and revealed preference data. *Transportation Letters*, *12*(3), 166–171. https://doi.org/10.1080/19427867.2018.1546806

Limtanakool, N., Dijst, M., & Schwanen, T. (2006). The influence of socioeconomic characteristics, land use and travel time considerations on mode choice for medium- and longer-distance trips. *Journal of Transport Geography*, *14*(5), 327–341. https://doi.org/10.1016/J.JTRANGEO.2005.06.004

Liu, X. (2016). Mixed-effects multinomial logit model for nominal outcomes. *Methods and Applications of Longitudinal Data Analysis*, 343–378. https://doi.org/10.1016/B978-0-12-801342-7.00011-3

Lo, H. K., Yip, C. W., & Wan, Q. K. (2004). Modeling competitive multi-modal transit services: a nested logit approach. *Transportation Research Part C: Emerging Technologies*, *12*(3–4), 251–272. https://doi.org/10.1016/J.TRC.2004.07.011

Lu, X.-Y., Gosling, G. D., Ceder, A., Tung, S., Tso, K., Shladover, S., Xiong, J., & Yoon, S. (2009). *A Combined Quantitative and Qualitative Approach to Planning for Improved Intermodal Connectivity at California Airports*.

Lukassen, R. (2023, September 29). Betaalde kiss & ride weer op tafel om Schiphol aan groei te helpen. *RTL Nieuws*.

Ma, T. Y., Gerber, P., Carpentier, S., & Klein, S. (2015). Mode choice with latent preference heterogeneity: a case study for employees of the EU institutions in Luxembourg. *Transportmetrica A: Transport Science*, *11*(5), 441–463. https://doi.org/10.1080/23249935.2015.1007175

Mahmoud, M. S., Weiss, A., & Habib, K. N. (2016). Myopic choice or rational decision making? An investigation into mode choice preference structures in competitive modal arrangements in a multimodal urban area, the City of Toronto. *Https://Doi.Org/10.1139/Cjce-2015-0336*, *43*(5), 420–428. https://doi.org/10.1139/CJCE-2015-0336

Marcus, J. (n.d.). *Hoe lang van te voren kun je het beste op Schiphol zijn?* EUclaim. Retrieved 30 April 2024, from https://www.euclaim.nl/blog/hoe-lang-van-te-voren-op-schiphol

McFadden, D. (1974). Conditional logit analysis of qualitative choice behavior. In *P. Zarembka*. Academic Press.

McFadden, D. (1975). Statistical Estimation of Choice Probability Functions. In T. Domencich & D. McFadden (Eds.), *Urban Travel Demand: A Behavioral Analysis* (pp. 101–125). North-Holland Publishing Company.

McFadden, D., & Train, K. (2000). MIXED MNL MODELS FOR DISCRETE RESPONSE. *Journal of Applied Econometrics*, *15*(5). https://doi.org/10.1002/1099-1255

Ministry of Infrastructure & Water Management. (2020). *Luchtvaartnota 2020-2050*.

Ministry of Infrastructure & Water Management. (2021). *Referentieprognoses LMS NRM 2021*.

Molloy, J., Becker, F., Schmid, B., & Axhausen, K. W. (2021). mixl: An open-source R package for estimating complex choice models on large datasets. *Journal of Choice Modelling*, *39*, 100284. https://doi.org/10.1016/J.JOCM.2021.100284

Molnár, H., & Konen, R. (2003). *Carpoolen in het woon-werkverkeer*.

Municipality of Amsterdam. (2019). *Uitgangspunten Verkeersmodel Amsterdam 3.0*.

NDC. (n.d.). *Snelheidsmetingen van ongehinderd rijdende fietspadgebruikers (2022 en 2023)*. Retrieved 14 May 2024, from https://www.ndc-nederland.nl/snelheidsmetingen-van-ongehinderd-rijdende-fietspadgebruikers-2022-en-2023/

NOS. (2020, August 28). Dieprode cijfers voor Schiphol, honderden banen weg. *NOS Nieuws*.

NS. (2023). *Spoorkaart 2023*.

Ortelli, N., Hillel, T., Pereira, F. C., de Lapparent, M., & Bierlaire, M. (2021). Assisted specification of discrete choice models. *Journal of Choice Modelling*, *39*, 100285. https://doi.org/10.1016/J.JOCM.2021.100285

Ortuzar, J. de D., & Willumsen, L. G. (2011). Introduction. In *Modelling Transport* (pp. 1–27). https://doi.org/https://doi.org/10.1002/9781119993308.ch1

Parady, G., & Axhausen, K. W. (2023). *Size Matters: The Use and Misuse of Statistical Significance in Discrete Choice Models in the Transportation Academic Literature*.

Parady, G., Ory, D., & Walker, J. (2021). The overreliance on statistical goodness-of-fit and under-reliance on model validation in discrete choice models: A review of validation practices in the transportation academic literature. *Journal of Choice Modelling*, *38*, 100257. https://doi.org/10.1016/J.JOCM.2020.100257

Parkcare. (2023). *Hoe ver van tevoren moet ik aanwezig zijn bij Schiphol?* Parkcare. https://parkcare.nl/blog/hoe-ver-van-tevoren-moet-ik-aanwezig-zijn-bij-schiphol

Pels, E., Nijkamp, P., & Rietveld, P. (2001). Airport and Airline Choice in a Multiple Airport Region: An Empirical Analysis for the San Francisco Bay Area. *Regional Studies*, *35*(1), 1–9. https://doi.org/10.1080/00343400120025637

Possel, B., De Graaf, S., & Brederode, L. (2020). The Mobility Spectrum: A data driven strategic transport model for the whole of The Netherlands. *EUROPEAN TRANSPORT CONFERENCE 2020*.

Pots, M. (2017). *Automatic parameter calibration in the strategic transport model of The Hague*.

Prato, C. G., Halldórsdóttir, K., & Nielsen, O. A. (2018). Evaluation of land-use and transport network effects on cyclists' route choices in the Copenhagen Region in value-of-distance space. *International Journal of Sustainable Transportation*, *12*(10), 770–781. https://doi.org/10.1080/15568318.2018.1437236

RDW. (2023, January 2). *Aantal benzine en diesel auto's nog ver aan kop*. Dienst Wegverkeer. https://www.rdw.nl/particulier/nieuws/2023/aantal-benzine-en-diesel-autos-nog-ver-aan-kop

Rijksoverheid. (2024, January 1). *Wat zijn de tarieven voor een taxi?* . https://www.rijksoverheid.nl/onderwerpen/taxi/vraag-en-antwoord/wat-zijn-de-kosten-voor-een-taxi

Roh, H.-J. (2013). Mode Choice Behavior of Various Airport User Groups for Ground Airport Access. In *The Open Transportation Journal* (Vol. 7).

Rothfeld, R., Straubinger, A., Paul, A., & Antoniou, C. (2019). Analysis of European airports' access and egress travel times using Google Maps. *Transport Policy*, *81*, 148–162. https://doi.org/10.1016/J.TRANPOL.2019.05.021

Savelberg, F. (2009). *Het scheiden van de markt: vraagontwikkeling in het personen- en goederenvervoer*. Kennisinstituut voor Mobiliteitsbeleid.

Schiphol Airport. (n.d.-a). *Schiphol Parking drive-up rates*. Retrieved 17 January 2024, from https://www.schiphol.nl/en/parking/prices/

Schiphol Airport. (n.d.-b). *Veelgestelde vragen over parkeren bij Schiphol*. Retrieved 14 March 2024, from https://www.schiphol.nl/nl/parkeren/faq-parkeren/

Schiphol Group. (2015). *2015, Facts & Figures*.

Schiphol Group. (2023). *Traffic review 2023*.

Schiphol Group. (2024). *Annual Report 2023*.

Schlesinger, S., Crosbie, R. E., Gagné, R. E., Innis, G. S., Lalwani, C. S., Loch, J., Sylvester, R. J., Wright, R. D., Kheir, N., & Bartos, D. (1979). Terminology for model credibility. *SIMULATION: Transactions of The Society for Modeling and Simulation International*, *32*(3), 103–104. https://doi.org/10.1177/003754977903200304

Schoemakers, A., & Geurs, K. (2008). Vroeger voorspelden we de toekomst beter. *Colloquium Vervoersplanologisch Speurwerk*.

Shires, J. D., & De Jong, G. C. (2009). *An international meta-analysis of values of travel time savings*.

Short, C. (2017, May 19). *Segmentation: Does it Impact Predictive Modelling Results for People Analytics?* https://www.linkedin.com/pulse/segmentation-does-impact-predictive-modelling-results-chris-short/

Significance. (2023). *AEOLUS Documentatie 2.0 Rapport voor Rijkswaterstaat WVL*.

Snelder, M., Tavasszy, L., Duijnisveld, M., Haaijer, R., Meurs, H., Van Nes, R., Verroen, E., Van Schie, C., Bates, J., & Jansen, B. (2012). *AUDIT LMS EN NRM Stap 3: fit for purpose*. www.tno.nl

Sobieniak, J., Westin, R., Rosapep, T., & Shin, T. (1979). Choice of Access Mode to Intercity Terminals. *Transportation Research Record*, *728*, 47–53.

Soza-Parra, J., Raveau, S., & Muñoz, J. C. (2022). Public transport reliability across preferences, modes, and space. *Transportation*, *49*(2), 621–640. https://doi.org/10.1007/s11116-021-10188-2

Stil, H. (2020, November 24). Ook hotelbussen van en naar Schiphol worden elektrisch. *Het Parool*. https://www.parool.nl/amsterdam/ook-hotelbussen-van-en-naar-schiphol-worden-elektrisch~bd2fcb56/?referrer=https://www.google.com/

Sweet, M. N., & Chen, M. (2011). Does regional travel time unreliability influence mode choice? *Transportation*, *38*(4), 625–642. https://doi.org/10.1007/S11116-011-9335-Z/TABLES/4

Swierstra, A. B., Van Nes, R., & Molin, E. J. E. (2017). Modelling travel time reliability in public transport route choice behaviour. *EJTIR Issue*, *17*(2), 263–278.

SWOV. (2022). *SWOV-factsheet Elektrische fietsen en speed-pedelecs*.

Terlouw, J. (2024). *Interview: Access modes to Schiphol Airport*.

Theiss, V., & Noll, L. (2022). The Effect of Price Changes in Luxury Goods. *Marketing Review St.Gallen*, *39*(1), 24–31. https://hdl.handle.net/10419/276173

Train, K. (2009). Discrete Choice Methods with Simulation. In K. Train (Ed.), *Discrete Choice Methods with Simulation* (2nd ed.). Cambridge University Press.

Tsamboulas, D., Evmorfopoulos, A. P., & Moraiti, P. (2012). Modeling airport employees commuting mode choice. *Journal of Air Transport Management*, *18*(1), 74–77. https://doi.org/10.1016/J.JAIRTRAMAN.2011.10.005

Ugba, E. R., & Gertheiss, J. (2023). A Modification of McFadden's R 2 for Binary and Ordinal Response Models. *Communications for Statistical Applications and Methods*, *30*, 49–63. https://doi.org/10.29220/CSAM.2023.30.1.049

Vakantie Discounter. (n.d.). *Hoe lang van tevoren moet ik op het vliegveld aanwezig zijn?* Retrieved 30 April 2024, from https://klantenservice.vakantiediscounter.nl/hc/nl/articles/360056756332-Hoe-lang-van-tevoren-moet-ik-op-het-vliegveld-aanwezig-zijn

van Velzen, J. (2024, February 1). E-bikes razen weer een beetje sneller over de wegen. *Trouw*. https://www.trouw.nl/duurzaamheid-economie/e-bikes-razen-weer-een-beetje-sneller-over-de-wegen~b387f844/

van Wingerden, M., & Kalenscher, T. (2022). Choice Behavior. *Encyclopedia of Computational Neuroscience*, 723–735. https://doi.org/10.1007/978-1-0716-1006-0_311

Wang, F., & Xu, Y. (2011). Estimating O–D travel time matrix by Google Maps API: implementation, advantages, and implications. *Annals of GIS*, *17*(4), 199–209. https://doi.org/10.1080/19475683.2011.625977

Wardman, M. (2022). Meta-analysis of price elasticities of travel demand in great britain: Update and extension. *Transportation Research Part A: Policy and Practice*, *158*, 1–18. https://doi.org/10.1016/J.TRA.2022.01.020

Wolfers, R. (2024). *Interview: Data RPM/mobiliteitsonderzoek*.

Wulff, J. N. (2015). Interpreting Results From the Multinomial Logit Model: Demonstrated by Foreign Market Entry. *Organizational Research Methods*, *18*(2), 300–325. https://doi.org/10.1177/1094428114560024

Zijlstra, T. (2020). A border effect in airport choice: Evidence from Western Europe. *Journal of Air Transport Management*, *88*, 101874. https://doi.org/10.1016/J.JAIRTRAMAN.2020.101874

Zinger, L. (2024). *Parkeerkosten personeel en gebieden op Schiphol*. Schiphol Parking & Mobility Services.

Zusman, M. E. (1973). *The Nature of Method Effects: a Comparison of the Personal Interview, Personal Questionnaire and the Mailed Questionnaire* [PhD defence, Indiana University]. https://www.proquest.com/openview/4022a71f6a59509dd6c4286d473a1c60/1?pq-origsite=gscholar&cbl=18750&diss=y

µ Consult. (2023). *Landelijk Reizigersonderzoek 2022*.

APPENDICES

APPENDIX I: EXPLANATORY VARIABLE SPECIFICATION PASSENGERS

This appendix dives deeper into the choices made in defining the explanatory variables, specifically for passengers. Again, the variables are introduced by means of the categories, variables related to the trip and related to the individual characteristics. No additional information on the variables related to the origin is provided.

VARIABLES RELATED TO THE TRIP

This section introduces how trip-related variables are defined in more detail. However, first, the difference between in- and out-of-vehicle travel time and why the latter is not included in the analysis is discussed.

OUT-OF-VEHICLE TRAVEL TIME

Travel time can be divided into in-vehicle time travel time and out-of-vehicle travel time and both contribute to explaining access mode choice (Hess & Polak, 2006; Jou et al., 2011; Sobieniak et al., 1979). In-vehicle travel time corresponds to the travel times as computed with the Mobility Spectrum. No information on the out-of-vehicle travel times was included, however a fixed value could be included, following the values presented in Table 4. Nonetheless, this is inappropriate in discrete choice models, as this constant acts as a second ASC. In that case, the MNL model cannot be solved analytically and a globally optimal solution is not guaranteed anymore. Thus, for out-of-vehicle travel time to be included, it must vary between individuals and alternatives. As this is not available in this study, out-of-vehicle travel times are excluded from this study.

PUBLIC TRANSPORT

The travel times from the Mobility Spectrum are used.

The travel costs are estimated following the function as introduced in Section 2.3.1.2.

CAR PARKING

The travel times provided through the Mobility Spectrum are used.

The parking costs differ between the parking spots across Schiphol Airport and depend on the duration of stay. The distribution on whether or not passengers reserved their parking spot and the distribution between parking sites available at P3 (P3 sheltered and P3 unsheltered) or Schiphol Centrum (P1, Excellence and P6 Valet) from the RPM is used to determine the average parking costs per duration of stay category. For non-reserved spots, the fees as provided for the specific parking site following Table 4 are used. For reserved spots, it is assumed that the reservation is done one month in advance. Using these reserved parking spots fees are estimated for periods from the 15th of March onwards.

BROUGHT BY CAR

The travel time is considered to be the same as for the car in general.

No travel costs are considered when being brought by car, as in line with Gunay & Gokasar (2021). They mention that it is often perceived as rude to pay the driver in case of a drop-off in their study area. This assumption is also considered for Schiphol Airport. In the case of using the drop-off facilities, no extra costs are considered. Parking costs are associated with parking when brought by car with a rate of € 2.30 per 20 minutes. Nonetheless, there is no information available on the parking time of the respondents. As a result, only an assumed average can be considered. Nonetheless, this causes model estimation problems thus the parking costs for brought by car parking are excluded from this study.

TAXI

For taxi, the same trip as for brought by car is considered, so it has the same travel time.

The costs are based on a fixed start fare, which increases with a kilometre- and time rate as suggested by Gunay & Gokasar (2021) in their study in Istanbul, Turkey. At first, the maximum fares as introduced by Rijksoverheid (2024) are considered. Nonetheless, it became apparent that the costs increase unrealistically fast compared to the other modes of transport. Possibly due to competitiveness, taxi companies do not use Dutch maximum fares. As a result, a linear fit between the Uber costs of travelling to Schiphol Airport from the central railway station of 15 Dutch cities[6] and the travel distance and time were considered. At first, a negative intercept was obtained, resulting in negative taxi costs on close ranges. By fixing the intercept at zero, more realistic taxi costs for close distances are obtained, while maintaining an adjusted R^2 value of 0.98. By fixing the intercept at zero, the influence of the travel time was fully captured by the travel distance and the final obtained equation is presented in Equation 7 with d the travel distance in kilometres.

$$C_{taxi} = 1.96d \qquad \text{Eq. 7}$$

Rental Car

Rental cars also exploit the travel time for cars as estimated by the Mobility Spectrum.

No costs are incorporated for rental cars. Rental cars are often not chosen for a trip to the airport solely, but rather as a consideration for the whole trip, including the costs of renting the car during the full trip. This consideration is extremely hard to capture, as little is known about the remainder of the trip and also this consideration does not match the scope of this study.

Variables related to the Individual Traveller

Travelling during night hours is estimated to be when someone arrives at Schiphol Airport between 22:00 and 7:00. This is estimated using the flight time and whether or not someone is flying to a Schengen destination. When flying to a Schengen destination, it is assumed that one arrives at the airport two hours in advance of the flight time, whereas three hours is considered for non-Schengen flights. There are no official arrival times in place, however various travel agencies and other organisations advise these arrival times (Marcus, n.d.; Parkcare, 2023; Vakantie Discounter, n.d.).

Appendix II: Explanatory Variable Specification Personnel

This appendix dives deeper into the choices made in defining the explanatory variables, specifically for personnel. For personnel, only the trip-related variables are described in more detail. First, the manipulation of the travel time of the Mobility Spectrum for specific working locations is introduced. Then, the definition of the travel time and costs are presented per access mode.

Manipulation of Travel Time and Distance

In contrast to passengers, personnel has various destinations on the Schiphol areal, which are classified following the nine working locations as presented in Figure 2. However, these zones do not fully correspond with the neighbourhood level on which the travel times and travel distances are known. For some, a corresponding neighbourhood is available, namely Fokker Business Park, Schiphol Rijk, Schiphol Noord-West and Schiphol Centrum. The remainder of the areas are reconstructed using the available neighbourhoods. The goal is not to mimic the travel time and distance fully but to have a comparison between the travel time and distance by the different modes that would also apply to a certain personnel destination. This is reasonable to assume as this study is about access mode choice and thus destination choice is excluded (Section 1.4.1). What neighbourhoods are used to represent personnel locations is presented in Table 16.

[6] Amsterdam, Rotterdam, The Hague, Utrecht, Amersfoort, Haarlem, Leiden, Zaandam, Hoofddorp, Zoetermeer, Almere, Enschede, Breda, Arnhem, Zwolle

TABLE 16: WORKING LOCATION TRAVEL TIME MANIPULATIONS

Personnel location	Corresponding Neighbourhood	Reason
Schiphol Centum	Schiphol (5084)	Overlapping
Schiphol Zuid	Schiphol (5084)	Travel times of corresponding neighbourhood are adapted to match travel time and distance to centroid of areal
Schiphol Noord-West	Badhoevedorp Omgeving (5043)	Overlapping
Schiphol Noord	Badhoevedorp Schuilhoeve (5052)	Travel times of corresponding neighbourhood are adapted to match travel time and distance to centroid of areal
Schiphol Oost	Oude Meer (5056)	Situated next to the same bus line and the same N232 road connection as Fokker Business Park. Therefore, travel time and distance assumed equal to corresponding neighbourhood
Technisch Areaal Oost	Oude Meer (5056)	Situated next to the same bus line and the same N232 road connection as Fokker Business Park. Therefore, travel time and distance assumed equal to corresponding neighbourhood
Fokker Business Park	Oude Meer (5056)	Overlapping
Schiphol Rijk	Schiphol Rijk (5055)	Overlapping
Schiphol Zuid-Oost	Rozenburg Noord (5058)	Travel times of corresponding neighbourhood are adapted to match travel time and distance to centroid of areal

Moreover, assumptions were made following the type of job of an individual response. It is assumed that office workers commute during peak hours, whereas the other types of jobs travel during off-peak hours and therefore experience corresponding travel times. Also, for the first group is it assumed that they only travel on working days and as a result, the travel time reliability is recalculated, but only for working days.

CAR DRIVING

The travel time and costs are estimated via the same procedure as for car parking for passengers considering the working location of personnel in the Schiphol areal. No parking costs are included as a result of the social agreement as presented in Section 3.1.1.

CARPOOLING

Again, the same general travel time for cars is used.

The travel costs are however assumed to be split among all occupants of the car, which are assumed to be two in this study. µ Consult (2023) assumed this also in their study of Dutch travel behaviour and it is close to the occupancy rate of 2.28 observed in Molnár & Konen (2003).

BICYCLE

The travel time as estimated by the Mobility Spectrum is used as travel time.

No direct travel costs are associated with using a regular bicycle.

SLOW MOTORISED TWO-WHEELERS

Compared to a regular bicycle, this alternative, including electric bicycles and mopeds, has a higher travel speed and thus a lower travel time. There exist multiple studies that examined the speed of regular bicycles compared to electric bicycles. From the Dutch perspective, NDC (n.d.) executed research at 15 locations in the Netherlands in which they used a hand radar to measure the speed of different types of bicycle path users and found that electric bicycles travers with around an 18.0% higher velocity (van Velzen, 2024). SWOV (2022) found an increase of 19.3% in velocity, but in contrast to the NDC, they considered the full trajectory in estimating the average speeds of both alternatives. As a result, the latter is used to manipulate the travel times observed via the Mobility Spectrum.

Also, for this alternative, no direct travel costs are included. For example, recharging the battery of electric bicycles comes with a price. However, at between € 0.10 and € 0.13 per recharge (Gazelle, n.d.), this is not substantial and is also expected that these costs are only considered to a limited amount by the user.

PUBLIC TRANSPORT IN GENERAL

The access and egress time are manipulated to match access/egress mode types used by personnel. Mobility Spectrum uses walking as access and egress mode with a speed of 4.8 km/h. KpVV (2006) mentions that both cycling and walking are the most prominent access modes in the Netherlands. However, Kager & Harms (2017) saw that bicycle usage is superior to walking as an access mode to public transport in the Netherlands for personnel. In the latter study, a combined average speed of 16.2 km/h was observed when using a bicycle as an access mode and walking as egress mode. Then, the access/egress time is manipulated using the combined average speed.

As the Mobility Spectrum only includes out-of-vehicle time, including access/egress time and transfer time but excluding initial waiting time, a proportion between the access/egress travel time and the transfer time is estimated using Savelberg (2009). Then, only the portion of the access/egress travel time is manipulated. Savelberg (2009) estimated the proportion of the total travel time spent during transfers and as access/egress travel time for trips shorter than 5 kilometres, between 5 and 25 kilometres and longer than 25 kilometres.

Following the same procedure as for passengers the travel costs are included.

APPENDIX III: UTILITY FUNCTION SPECIFICATION GLOBAL MODEL PASSENGERS

PUBLIC TRANSPORT

$$U_{pt} = ASC_{pt} + \beta_{pt,TT} * ivTT_{PT} + \beta_{pt,C} * C_{PT} + \beta_{mode,holiday} * P_{holiday} + \beta_{pt,visrel} * P_{visrel} + \beta_{pt,business} * P_{business} + \beta_{pt,schengen} * DS + \beta_{pt,TD_{14\to20}} * TD_{14\to20} + \beta_{pt,age_{11-20}} * Age_{11-20} + \beta_{pt,age_{21-30}} * Age_{21-30} + \beta_{pt,age_{31-60}} * Age_{31-60} + \beta_{pt,age_{61\to80}} * Age_{61\to80} + \beta_{pt,resident-holiday} * P_{holiday} * RT$$

CAR PARKING AT SCHIPHOL CENTRUM

$$U_{car_{P_{SC}}} = ASC_{car_{P_{SC}}} + \beta_{car_{P_{SC}},TT} * ivTT_{car} + \beta_{car_{P_{SC}},C} * C_{car} + \beta_{C_{P_{SC}}} + C_{parkSC} + \beta_R * R + \beta_{car_{P_{SC}},gender} * G + \beta_{car_{P_{SC}},resident} * RT + \beta_{car_{P_{SC}},age_{21-30}} * Age_{21-30} + \beta_{car_{P_{SC}},age_{31-60}} * Age_{31-60}$$

CAR PARKING AT P3

$$U_{car_{P_{P3}}} = ASC_{car_{P_{P3}}} + \beta_{car_{P_{P3}},TT} * ivTT_{car} + \beta_{car_{P_{P3}},C} * C_{car} + \beta_{C_{P_{P3}}} + C_{parkP3} + \beta_R * R + \beta_{car_{P_{P3}},gender} * G + \beta_{car_{P_{P3}},resident} * RT + \beta_{car_{P_{P3}},schengen} * DS + \beta_{car_{P_{P3}},age_{11-20}} * Age_{11-20} + \beta_{car_{P_{P3}},age_{21-30}} * Age_{21-30} + \beta_{car_{P_{P3}},age_{31-60}} * Age_{31-60}$$

BROUGHT BY CAR, PARKING

$$U_{car_{P_{kr}}} = ASC_{car_{P_{kr}}} + \beta_{car_{P_{kr}},TT} * ivTT_{car} + \beta_R * R + \beta_{car_{P_{kr}},holiday} * P_{holiday} + \beta_{car_{P_{kr}},business} * P_{business} + \beta_{car_{P_{kr}},gender} * G + \beta_{car_{P_{kr}},schengen} * DS + \beta_{car_{P_{kr}},night} * NT + \beta_{car_{P_{kr}},TD_{1-3}} * TD_{1-3} + \beta_{car_{P_{kr}},TD_{14\to20}} * TD_{14\to20} + \beta_{car_{P_{kr}},age_{11-20}} * Age_{11-20} + \beta_{car_{P_{kr}},age_{21-30}} * Age_{21-30} + \beta_{car_{P_{kr}},age_{31-60}} * Age_{31-60}$$

BROUGHT BY CAR, DROP-OFF

$$U_{car_{d_{kr}}} = ASC_{car_{d_{kr}}} + \beta_{car_{d_{kr}},TT} * ivTT_{car} + \beta_R * R + \beta_{mode,holiday} * P_{holiday} + \beta_{mode,business} * P_{business} + \beta_{mode,conference} * P_{conference} + \beta_{mode,resident} * RT + \beta_{mode,schengen} * DS + \beta_{mode,night} * NT + \beta_{mode,TD_{1-3}} * TD_{1-3} + \beta_{mode,TD_{4-13}} * TD_{4-13} + \beta_{mode,TD_{14\to20}} * TD_{14\to20} + \beta_{mode,age_{11-20}} * Age_{11-20} + \beta_{mode,age_{21-30}} * Age_{21-30} + \beta_{mode,age_{31-60}} * Age_{31-60} + \beta_{mode,resident-holiday} * P_{holiday} * RT$$

TAXI

$$U_{taxi} = ASC_{taxi} + \beta_{taxi,TT} * ivTT_{car} + \beta_{taxi,C} * C_{taxi} + \beta_R * R + \beta_{mode,holiday} * P_{holiday} + \beta_{mode,business} * P_{business} + \beta_{mode,resident} * RT + \beta_{mode,schengen} * DS + \beta_{mode,night} * NT + \beta_{mode,TD_{1-3}} * TD_{1-3} + \beta_{mode,TD_{4-13}} * TD_{4-13} + \beta_{mode,TD_{14\to20}} * TD_{14\to20} + \beta_{mode,age_{21-30}} * Age_{21-30} + \beta_{mode,age_{31-60}} * Age_{31-60} + \beta_{mode,age_{61\to80}} * Age_{61\to80} + \beta_{mode,resident-holiday} * P_{holiday} * RT + \beta_{mode,resident-business} * P_{business} * RT$$

RENTAL

$$U_{rental} = ASC_{rental} + \beta_{rental,TT} * ivTT_{car} + \beta_R * R + \beta_{mode,business} * P_{business} + \beta_{mode,gender} * G + \beta_{mode,resident} * RT + \beta_{mode,TD_{1-3}} * TD_{1-3} + \beta_{mode,TD_{4-13}} * TD_{4-13} + \beta_{mode,TD_{14\to20}} * TD_{14\to20} + \beta_{mode,resident-holiday} * P_{holiday} * RT + \beta_{mode,resident-business} * P_{business} * RT$$

APPENDIX IV: SEGMENTED PASSENGER MODEL

This appendix dives deeper into the passenger models estimated for specific segments. In total, four segmented models are estimated; resident – leisure (R-L), resident – business (R-B), international – leisure (I-L) and international – business (I-B). The parameter value estimates presented in Table 17 indicate the change in utility for a specific alternative when a certain variable is increased by 1 unit. The columns represent the parameter value estimates for a specific segment compared to the global model (G). It should be noted that some dummy variables of the global model are not included in the segmented models, for example trip purpose, as the dummies are substituted by estimating a model for a specific segment. As a result, only the overlapping subsection of the global model is presented for comparison.

The remainder of this section first describes the interpretation of the parameter value estimates and corresponding signs in more detail and dives deeper into the steps to validate the model. This appendix concludes with a synthesis of why segmented models do not outperform the global model.

TABLE 17: RESULTS OF THE SEGMENTED MODELS FOR PASSENGERS

Parameter [unit]	G	R-L	I-L	R-B	I-B
Alternative Specific Constant					
Public transport					
Car parking at SC	-5.36	-4.09	-6.58	-1.95	-5.31
Car parking at P3	-6.06	-3.63	-6.33	-2.45	-5.13
Brought by car, parking	-3.76	-4.31	-4.51	-5.26	-4.38
Brought by car, drop-off	-1.19	-1.28	-2.52	-1.50	-1.56
Taxi	-1.09	-1.87		-0.72	
Rental	-3.33	-4.23	-3.62	-5.51	-2.40
Travel Time [1/h]					
Public transport	-1.36	-1.40	-1.84	-1.08	-2.16
Car parking at SC	-1.39	-1.37	-2.76	-2.44	-2.37
Car parking at P3	-1.33	-1.39	-4.02	-0.94	-2.56
Brought by car, parking	-3.13	-3.50	-2.71	-3.14	-3.09
Brought by car, drop-off	-3.89	-4.26	-3.37	-4.02	-3.16
Taxi	-0.98	-0.68	-7.88	-5.28	-4.50
Rental	-2.91	-4.49	-3.08	-3.59	-2.03

Note: The parameters reported in the table were statistically significant on a 99% confidence level. When marked by an asterisk (*) the parameters was found only statistically significant on a 95% confidence level – ***Table continues on next page***

Parameter [unit]	G	R-L	I-L	R-B	I-B
Travel Costs [1/€]					
Public transport	-0.10	-0.12	-0.11*	-0.09	
Car parking at SC	-0.09	-0.12			
Car parking at P3	-0.07	-0.09		-0.09*	
Taxi	-0.03	-0.03			
Parking Costs [1/€]					
Schiphol Centre	-0.005	-0.001*		-0.011	
P3	-0.006	-0.002*		-0.011	
Travel Time Reliability [1/h]					
Reliability car network	3.54	3.80		7.49	
Accessibility [1/km]					
Distance to highway					
Distance to train station					
Distance to Intercity train station					
Duration of stay					
4-13 days[7] [boolean]					
Public transport		-0.58			
Car parking at SC					
Car parking at P3					
Brought by car, parking					
Brought by car, drop-off	0.32			0.30	-1.24
Taxi	0.12				-0.37
Rental	0.25	-1.55			-0.17*
14->20 days[7] [boolean]					
Public transport					
Car parking at SC					
Car parking at P3					
Brought by car, parking	1.20	1.43		2.15	
Brought by car, drop-off	0.74	0.82		0.76	
Taxi	0.49	1.04			
Rental	0.60			1.91	-0.38*
Other Individual Characteristics					
Schengen destination [boolean]					
Public transport	0.21	0.32			0.37
Car parking at SC					
Car parking at P3	0.15	0.21		0.32*	
Brought by car, parking	-0.61	-0.70	-0.70		
Brought by car, drop-off	-0.27	-0.29			
Taxi	-0.22		-0.41	-0.52	
Rental					
Night travelling [boolean]					
Public transport		0.29	-0.69		-0.38
Car parking at SC		0.31			
Car parking at P3		0.35		-0.68	
Brought by car, parking	-0.24				
Brought by car, drop-off	-0.12			-0.54	
Taxi	0.31	0.31			
Rental					

Note: The parameters reported in the table were statistically significant on a 99% confidence level. When marked by an asterisk (*) the parameters was found only statistically significant on a 95% confidence level – ***Table continues on next page***

[7] Staying for 1-3 days being the reference group

Parameter [unit]	G	R-L	I-L	R-B	I-B
Gender [boolean]					
Public transport					0.25
Car parking at SC	-0.42	-0.17*		-0.70	
Car parking at P3	-0.16			-0.88	-2.48
Brought by car, parking	0.47	0.48	0.46	0.74	
Brought by car, drop-off		0.12			
Taxi					
Rental	-0.45		-0.38		
Age 11-20 years[8] [boolean]					
Public transport	0.29	0.44			
Car parking at SC					-1.81
Car parking at P3	-0.88	-0.79		-4.06	-1.22
Brought by car, parking	1.03	1.21		2.03	2.32
Brought by car, drop-off	0.47	0.55		0.85	
Taxi					
Rental					
Age 21-30 years[8] [boolean]					
Public transport	0.64	0.52	0.39	0.25*	
Car parking at SC	-0.69	-0.91		-0.86	
Car parking at P3	-0.64	-0.81		-0.93	
Brought by car, parking	0.79	0.63		1.04	1.12
Brought by car, drop-off	0.36	0.18			
Taxi	0.31		0.19		
Rental			-0.66		
Age 61->80 years[8] [boolean]					
Public transport	-0.26		-0.68		
Car parking at SC					
Car parking at P3		0.18*			
Brought by car, parking					
Brought by car, drop-off		0.13			
Taxi	0.17	0.33			
Rental					
Summary statistics					
McFadden R	0.380	0.344	0.439	0.349	0.381
Adjusted McFadden R	0.379	0.343	0.438	0.344	0.378
Sample size	33508	15971	9759	3883	3897

Note: The parameters reported in the table were statistically significant on a 99% confidence level. When marked by an asterisk (*) the parameters was found only statistically significant on a 95% confidence level

IV.I Interpretation of Results

Resident – Leisure

The resident – leisure model shows large similarities with the global model in terms of parameter value estimate proportions. Nonetheless, there are subtle differences. When observing the parameter value estimates for travel costs and parking costs, the same proportions, but more extreme, are observed for the resident – leisure model, compared to the global model. It is plausible that longer durations of stay affect this, as the ratio between the travel costs and parking costs increases. 35.0% of the trips in the resident – leisure estimation dataset have a duration longer than 14 days, whereas this is only 27.2% in the global model. Moreover, the effect of a night flight on the access mode choice is notable. It is surprising to observe the implied preference for public transport during night hours. When observing this group of resident travellers with a leisure purpose using public transport, it becomes apparent that they often have a flight in the early morning (7:00 till 9:00) and often originate from the Randstad area. The municipalities of Amsterdam, Rotterdam, The Hague and Utrecht comprises 52% of this group. As mentioned, the public transport services to Schiphol Airport in the Randstad area operate with a high

[8] Aging between 31 and 60 being the reference group

frequency and also start early with their timetable, making public transport also a viable option in the early morning.

International – Leisure

For the international – leisure segment it became apparent that the travel costs for both car parking alternatives and for taxis, as well as the parking costs for both car parking alternatives were statistically insignificant. Travel costs are for most alternatives statistically insignificant for international – leisure travellers. On the one hand, private car alternatives are rarely used by international travellers, explaining why the travel and parking costs do not influence the utility for these alternatives. On the other hand, international – leisure travellers originate for 75% from Amsterdam and costs for travelling to Amsterdam are relatively low compared to the airfare and/or accommodation fares. Also, the high correlation between the travel costs and travel time in general for all access modes can contribute to the insignificance of the travel costs. Moreover, this particular segment is not sensitive to the duration of stay. The duration of stay for international travellers refers to how long they have been staying in the Netherlands and, apart from rental cars, the travel costs are not influenced by how many days someone stays. Besides that, international travellers in general do not prefer to use public transport at night. International air travellers are less familiar with the public transport network of the Netherlands and might not be informed about the availability of public transport at night for certain origins in the Randstad area.

Resident – Business

For resident – business travellers also the travel costs for taxi are statistically insignificant. Business travellers in general often care less about the costs of travelling as their employer pays this most of the time (Hess & Polak, 2006). For travellers with a business purpose, in general, holds that the access mode choice is insensitive for the oldest age class, as this age group is relatively small. It was expected that for the youngest age group with a business purpose, the same would hold, however they have a clear preference for being brought by car. It was notable that of this small group, 54% had a duration of stay longer than 20 days and even 30% longer than 100 days, e.g., exchange students. For longer durations of stay, it is expected that parents want to take time to say farewell, hence explaining the preference for brought by car, parking. For the 21-30 age class, parking is less favoured as also found in Gupta et al. (2008). Besides low car ownership, Gupta et al. (2008) contributes this to younger people being in entry positions for their employer, imposing budget restrictions for travelling. For travellers with a business purpose in general a higher positive magnitude is observed for being brought by car. Business travellers often make use of private chauffeurs, which is associated with a high level of comfort, possibly explaining this preference.

International – Business

International – business travellers share the same travel and parking costs parameters being statistically insignificant as international – leisure travellers. In contrast to leisure travellers, also public transport costs are statistically insignificant for business travellers. Possibly international – business travellers are less sensitive to travel costs as found in the literature (Hess & Polak, 2006). Another contrasting aspect is the influence of the duration of stay. Whereas the access mode choice of international leisure travellers is not sensitive to the length of stay, it is of international business travellers. For the longest durations of stay, the rental costs of a rental car might play a role in explaining why they are less preferred. Also, for international business travellers the youngest age group has a specific preference for the access mode brought by car, parking, despite being a very small group (1.8%). Again, a relatively large share of long durations of stay are observed, suggesting that we again have to do with exchange students or similar. Also, in their case, it is plausible that more time is reserved for the farewell.

IV.II. Validation of Explanatory Power

Value of Time Savings

In Table 18, the value of time savings for the segmented models and the global model are presented and compared to the values obtained in KiM (2023). In their stated preference study, they made a distinction between the value of time savings for business and other purposes. In the case of airport access, it is assumed that the purposes categorised as other all have a leisure motive.

TABLE 18: VALUE OF TIME COMPARISON FOR DIFFERENT SEGMENTS FOR PASSENGERS

Access Mode	Global [€/h]	Leisure [€/h]			Business [€/h]		
		Resident	Internat.	KiM	Resident	Internat.	KiM
Public transport	13.2	11.6	17.3	8.26	12.0	*	15.02
Car parking at P3	18.0	15.1	*	13.9	*	*	31.49
Car parking at Schiphol Centrum	14.8	11.8	*		10.4	*	
Brought by car	-	-	-	11.12	-	-	18.59
Taxi	36.6	22.0	*	13.72	*	*	35.62

** Either/both the travel costs or time parameters were statistically insignificant, so no value of time savings was available*

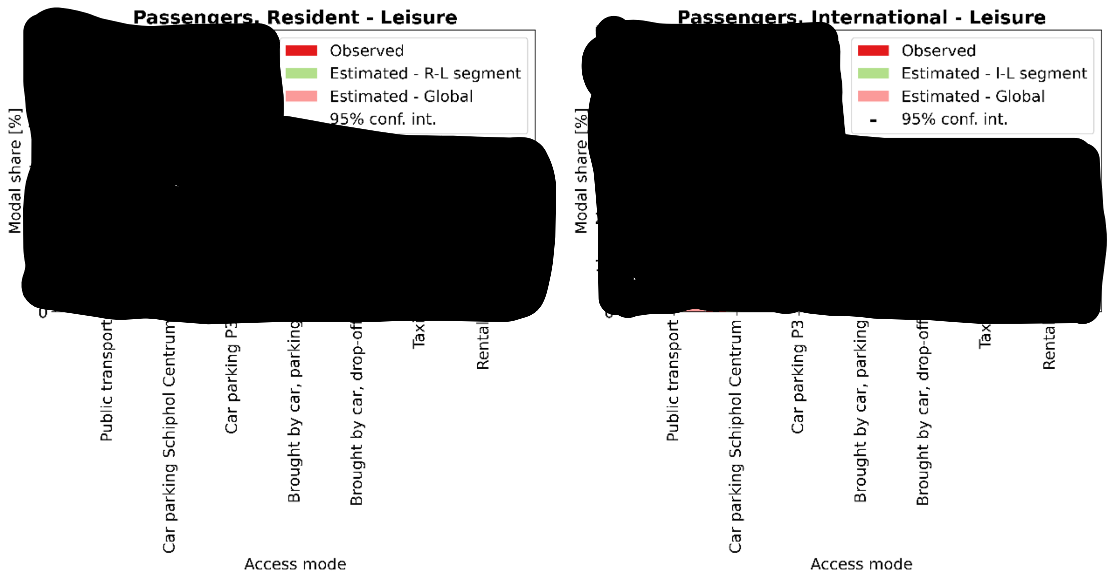
As a result of the insignificance of travel costs for many access modes for a few segmented models, many gaps are observed in the above-mentioned table. This does not allow for overarching conclusions from this table. What is noted from the table is that the proportion in the values of time savings for the resident – leisure segments is as expected. Having a lower budget, this group is less willing to pay to reduce their travel time. International - leisure travellers are more willing to pay to reduce their travel time by public transport. International leisure travellers are in the Netherlands to spend the holiday or to visit relatives. These activities are possibly valued highly. As a result, they are willing to spend more to increase time for these activities by reducing their travel time. For resident – business travellers, the value of time savings for public transport is higher than for the corresponding leisure group as in line with KiM (2023), following business travellers value their work time highly (Hess & Polak, 2006). Counterintuitively, the value of time savings for parking at Schiphol Centrum is lower for business travellers compared to leisure travellers. Possibly, the more extreme effect of parking fares contributes. Also, a fuel card paid by the employer could explain the lower value of time savings.

GOODNESS-OF-FIT

The goodness-of-fit for all segmented models remained decent to excellent (Hensher et al., 2015, Chapter 7; McFadden, 1975). However, due to the usage of different datasets, the adjusted McFadden R^2 cannot be used in a comparison context.

MARKET SHARES

The market shares are estimated using segments of the validation dataset. The results are presented in Figure 29.



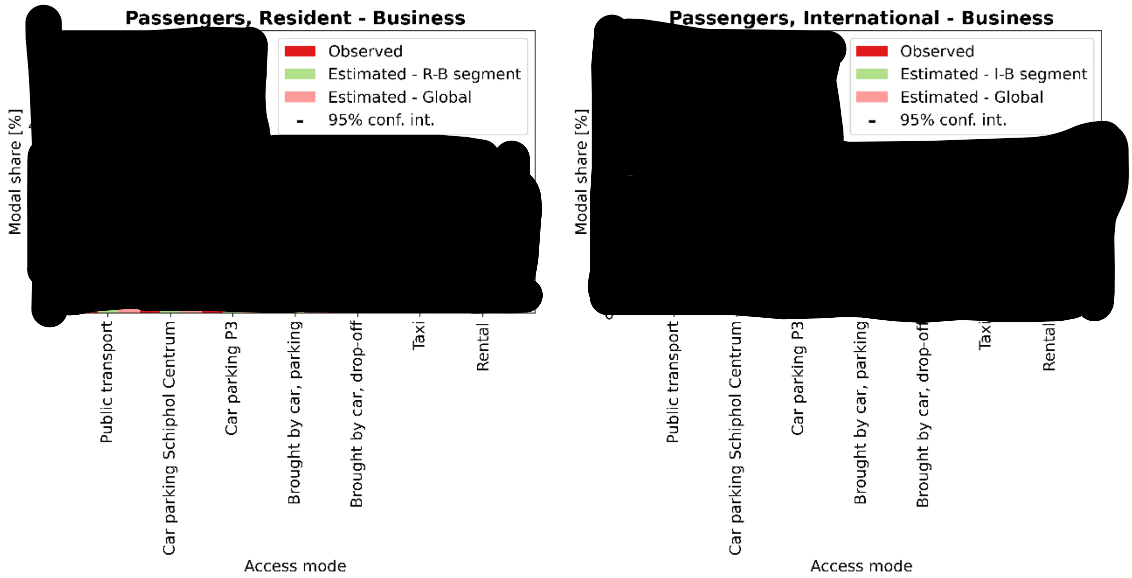


FIGURE 29: SPECIFIC MARKET SHARE FOR GLOBAL AND SEGMENTED MODEL FOR TOP LEFT) RESIDENT – LEISURE; TOP RIGHT) INTERNATIONAL – LEISURE; BOTTOM LEFT) RESIDENT – BUSINESS; AND BOTTOM RIGHT) INTERNATIONAL – BUSINESS

The figure illustrates a difference in modal share between the segments. The global model performs reasonably well in estimating the modal share for all segments, just as the segmented models. Small differences between observed and estimated modal shares are potentially explained by the use of dummy variables for residence and trip purpose in the global model, allowing for explicitly modelling access mode choice preferences.

IV.III. Synthesis

This section introduced the estimation of segmented passenger models based on a combination of trip purpose and residence. Between the different segments, there exists differences in which explanatory variables affect access mode choice and by what magnitude. From the market shares became apparent that there is indeed a difference in modal share between the segments. However, the segmented models did not perform substantially better compared to the global model in estimating the modal share. The high performance on several segments even contributes to the validation of the global model, hence the global model is employed in the model application phase for passengers.

Appendix V: Utility Function Specification Global Model Personnel

Car Driver

$$U_{car_{driver}} = ASC_{car_{driver}} + \beta_{car_{driver},TT} * ivTT_{car} + \beta_{car_{driver},C} * C_{car} + \beta_{d_{highway}} * D_{highway} + \beta_{car_{driver},W_{office}} * W_{office} + \beta_{car_{driver},W_{shift(day)}} * W_{shift(day)} + \beta_{car_{driver},WfS_{2-4}} * WfS_{2-4} + \beta_{car_{driver},L_{SC}} * L_{SC} + \beta_{car_{driver},L_{BU}} * L_{BU} + \beta_{car_{driver},G} * G + \beta_{car_{driver},age_{40-54}} * Age_{40-54} + \beta_{car_{driver},age_{>55}} * Age_{>55}$$

Car Pooling

$$U_{car_{pooling}} = ASC_{car_{pooling}} + \beta_{car_{pooling},TT} * ivTT_{car} + \beta_{d_{highway}} * D_{highway} + \beta_{car_{pooling},W_{office}} * W_{office} + \beta_{car_{pooling},W_{aviation}} * W_{aviation} + \beta_{car_{pooling},WfS_{2-4}} * WfS_{2-4} + \beta_{car_{pooling},WfS_{5->5}} * WfS_{5->5} + \beta_{car_{pooling},L_{BU}} * L_{BU} + \beta_{car_{pooling},age_{40-54}} * Age_{40-54}$$

Bicycle

$$U_{bicycle} = \beta_{bicycle,TT} * ivTT_{bicycle} + \beta_{bicycle,WfS_{2-4}} * WfS_{2-4} + \beta_{bicycle,L_{SC}} * L_{sc} + \beta_{bicycle,G} * G + \beta_{bicycle,age_{40-54}} * Age_{40-54} + \beta_{bicycle,age_{>55}} * Age_{>55}$$

Slow motorised two-wheeler

$$U_{SMTW} = ASC_{SMTW} + \beta_{SMTW,TT} * ivTT_{SMTW} + \beta_{SMTW,W_{shift}} * W_{shift} + \beta_{SMTW,WfS_{2-4}} * WfS_{2-4} + \beta_{SMTW,L_{BU}} * L_{BU} + \beta_{SMTW,G} * G + \beta_{SMTW,age_{40-54}} * Age_{40-54} + \beta_{SMTW,age_{>55}} * Age_{>55}$$

TRAIN

$$U_{train} = \beta_{train,TT} * ivTT_{PT} + \beta_{train,C} * C_{PT} + \beta_{d_{station}} * D_{station} + \beta_{d_{ICstation}} * D_{ICstation} + \beta_{train,W_{office}} * W_{office} + \beta_{train,WfS_{2-4}} * WfS_{2-4} + \beta_{train,L_{BU}} * L_{BU} + \beta_{train,G} * G + \beta_{train,age_{18-24}} * Age_{18-24} + \beta_{train,age_{40-54}} * Age_{40-54}$$

BUS

$$U_{bus} = ASC_{bus} + \beta_{bus,TT} * ivTT_{PT} + \beta_{bus,C} * C_{PT} + \beta_{d_{station}} * D_{station} + \beta_{d_{ICstation}} * D_{ICstation} + \beta_{bus,W_{aviation}} * W_{aviation} + \beta_{bus,WfS_{2-4}} * WfS_{2-4} + \beta_{bus,L_{SC}} * L_{sc} + \beta_{bus,L_{BU}} * L_{BU} + \beta_{bus,G} * G + \beta_{bus,age_{18-24}} * Age_{18-24} + \beta_{bus,age_{25-39}} * Age_{25-39} + \beta_{bus,age_{40-54}} * Age_{40-54}$$