A. Montes Rojas

Studying mode choice in multimodal networks including shared modes

A case study for the city of Rotterdam

TU Delft

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A case study for the city of Rotterdam

By

Alejandro Montes Rojas

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Thesis committee:	Prof. dr. ir. S.P. Hoogendoorn	TU Delft, chair
	Dr. ir. N. van Oort	TU Delft, supervisor
	Dr. WW. Veeneman	TU Delft, supervisor
	Nejc Gerzinic	TU Delft, supervisor
	P. Koot	RET, external supervisor

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PREFACE

This report is the result of my graduation thesis, in which I have been working in the last eight months, and which represents the final stage of my time as a Master candidate in Transport, Infrastructure and logistics in the Delft University of Technology. Both this thesis and the Master's programme, in general, have been great but challenging. With this words, I want to thank those who make this possible in one or another way.

First of all, thanks to my Mother. Since very early in my life you planted in me the ambition of always aiming at the highest, it has applied for my personal life as well as for my academic formation. You have shown me the way here for many years, and thanks to that is that I can be finishing this project and with it this amazing experience. You have been the most constant and greatest support under all conditions. Thanks for making this a reality, this achievement is yours as much (or even more) as it is mine. To the rest of my family, thanks for all the support and for filling me with energy and happiness in the few times I could see you during these two years.

I would also like to express my gratitude to my graduation committee, you all helped me in a great way to be able to succeed with this challenging but really nice project. To Niels and Wijnand, after the Design project, I knew that I wanted you to be my thesis supervisors. Thanks for your constant support throughout all these months. There were a couple of critical moments in which I felt things falling apart, but you always helped me to find the right solutions and to redirect this project in the best way. To Patty, thanks for your constant great attitude, and for allowing me to know a bit more about the professional world in a company like RET. To Nejc, thanks for agreeing to join this project, and for the constant advice, support and even availability. Your knowledge and your constant help were key for the success of this research. Finally, from the University I also want to thank Danique and Florian. You were there the times I needed you, and your help was also very important.

Being away from home is always a challenge, you might feel fragile or lonely sometimes, yet for me, it was never the case. Lastly, I want to thank those responsible for that. Thanks to Camila, for being an amazing companion during these years despite the thousands of miles between us. Talking to you through a screen became a very nice part of my days. To my friends in the Netherlands, you have made this experience one of the best of my life, thanks for making me feel at home here. A special mention to Rafa, Male, Diego and Mateo, you guys became a family for me here and I'm sure that it will remain this way over time.

Alejandro Montes Rojas

Delft, October 2021

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Studying mode choice under transit and shared mobility integrated networks: A case study for the city of Rotterdam

Alejandro Montes Rojas[1]

[1]*Delft University of Technology, Delft, The Netherlands*

October 21, 2021

Following the emergence of new mobility trends, in which shared mobility plays an essential role, Public transport operators face the challenge of reacting in a convenient way to the changes brought to the transportation scene. Even though different collaborations are being put in place between public operators and shared mobility providers, the effects they may have in mode choice are still uncertain, and to the best of the author's knowledge still to be studied. Accordingly, a stated choice experiment was conducted in the city of Rotterdam, in which preferences towards shared bicycles and shared mopeds were analysed under the assumption of a perfect integration between transit and shared mobility. The results suggest that under said conditions, shared modes have the potential to be interesting egress alternatives for trips by metro, hence improving preferences towards the metro. Furthermore, considering choice determinants exhibited during the experiment, it is noticed that egress cost and total travel time are key aspects for traveller's choices. Finally, young people, respondents that claimed having used shared modes before, and frequent transit users showed a better perception of shared modes.

1 INTRODUCTION

In recent years, shared modes (SM) have emerged in cities with the support of emerging technologies as a response to the challenge of creating more sustainable cities. However, this represents a challenge to public transport operators, who need to react to the presence of the new players in the mobility scene. Accordingly, they need to make numerous decisions that include amongst other things whether to collaborate or not with other mobility providers, whether to develop or not their shared systems and in both cases how to design the integration of the different types of services. To do so, they first need to understand how these new modes relate to their existing traditional systems (*e.g., bus, metro train*). At the moment, this is still unclear. On the one hand, shared modes can compete with Public transport modes, and as such decrease their ridership. But on the other hand, they can also complement each other.

Previous studies have suggested that the relationship between shared modes and public transport highly depends on how well integrated the modes are. For instance, to encourage multimodality (integrating Public transport and shared modes), conditions to make shared modes available for access and egress should be met. As stated by Böcker et al. (2020), shared-mobility use frequencies are positively affected by the proximity of route ends to public transport stops. Likewise, Yan et al. (2020) highlight the importance of land use and population density around public transport stations for the adoption of bike-sharing. Pricing schemes and payment mechanisms are also considered relevant. It is argued that uniform ticketing systems, as well as integrated mobile phone apps, might improve integration as they allow the integration of real-time data, hence making transfers more efficient and improving user-friendliness (Böcker et al., 2020; Ma et al., 2020; Oeschger et al., 2020; Shaheen, 2016).

According to the latter, and considering the need or public transport operators of understanding how potential collaborations might affect them, this paper studies the potential relationship of public transport and shared modes (more specifically shared mopeds and shared bicycles), under the scenario of shared modes and public transport being perfectly integrated in terms of trip planning, availability of shared vehicles in transit stations and payment systems. The study aims at analysing how mode choice could be affected by the integration of modes under said hypothetical scenario in the context of trips originated at home and reaching an activity destination. Two types of purpose for shared modes are included: on the one hand, they are analysed as egress modes from metro trips in which they compete with local public transport and walking; and on the other hand, shared mopeds are studied as an alternative for the whole trip from origin to destination, thus competing with metro and other modes.

The relationship between shared modes and public transport has been widely studied in recent years. While some academics have based their studies on analysing whether shared modes are competition or complement transport, some others have instead studied the use of shared modes as a whole, from which they conclude its (potential) synergy with transit. Even though conclusions vary among studies, many agree on the potential of the combination of public transport with shared modes, to achieve more sustainable mobility in urban environments (Ferrero et al., 2018; Hardt & Bogenberger, 2019; Machado et al., 2018; Meng et al., 2020; Oeschger et al., 2020).

According to Oeschger et al. (2020), the integration of shared micro-mobility with public transport treated as a distinct mode could be seen as a sustainable transport mode. Especially considering that it takes the best of both modes, hence combining their strengths and advantages. While shared micro-mobility can offer flexibility and efficient accessibility, public transport offers higher speeds and larger spatial coverage. Two strong arguments arise supporting the idea of shared modes being a potential complement to PT. First, shared modes can serve as access/egress modes, and as such help improve the accessibility to public transport (Böcker et al., 2020; Oeschger et al., 2020; van Kuijk et al., 2021). Secondly, by improving access/egress to public transport, shared modes can help to increase coverage of public transport networks, as the catchment are of stations is improved. Furthermore, shared modes could help to manage public transport demand, by for example reducing overcrowding or helping to integrate different modes and serving sporadic travel needs that cannot be properly served with traditional public transport modes (Böcker et al., 2020; McLeod et al., 2017; Ricci, 2015).

Nonetheless, some academics argue that SM do not only complement but also compete against PT. Leth et al. (2017) for example highlight that according to their study, in high-density areas bike-sharing represents a direct and faster option against the use of public transport. Something similar holds for congested parts of public transport networks, like city centres, where shared modes can offer lower travel times and costs compared to public transport (Machado et al., 2018). Long travel times by public transport are an important deterrent to the use of these modes, as such, they might encourage switches to shared modes as long as the latter are considerably faster (Leth et al., 2017). For instance, regarding bike sharing Ricci (2015) claims that it can at the same time complement and substitute public transport.

To sum up, the relationship between public transport and shared modes is rather complex, and whether it is complementary or synergetic depends on various factors. Even though different studies have been performed in recent years to understand this relationship, they have mostly focused on analysing the current use of SM and the perception of users towards them. It can be argued that it is also of great importance to understand the underlying reasons that result in said use and perceptions, which are usually captured in mode choice studies. Subsequently, some studies have been performed studying mode choice involving SM and PT. However, such research has been often limited to analysing first/last mile travel. As a result, those studies have ignored the effects of SM for the overarching choice of using PT or not, as well as how they compete against each other. Including said relationships might be relevant to understand if potential modal shifts can occur as a result of an improvement in PT services due to the presence of SM, and thus if the integration of modes is potentially beneficial.

Accordingly, this paper deals with these gaps in the literature as it first does not only include analysis of shared modes as first/last mile enablers but also as alternatives for trips from origin to destination; and second, it explores the overall mode choice from origin to destination, in which the effect for the public transport of the presence of shared modes as egress options can be evaluated. Overall, the methodology of the project consists of the development of a stated choice experiment, and a subsequent mode choice model in which the data collected is used as input. The study is performed taking as an example the city of Rotterdam in The Netherlands, in which different transport alternatives coexist: *metro, tram, bus, shared bicycles, shared mopeds, cars, bicycles, etc*.

The remaining of this paper is structured as it follows: Section 2 presents the most relevant aspects of the stated choice experiment. Section 3 describes the survey, while Section 4 presents the overview of the results obtained. Finally, Section 5 presents the definition and estimation of Discrete choice models and Section 6 presents the main conclusions of the study.

2 STATED CHOICE EXPERIMENT

A 2-step approach is defined for the experiment. It includes two transport mode decisions related to one another, for each choice situation. Each situation assumes a trip from home to a leisure/commute destination within the city. For the first choice(step 1) it is assumed a multimodal trip -only main leg and egress- in which the first part of the trip is travelled by train. The respondents face a choice task in which they are asked to specify their preferred egress mode (see Figure 1). This choice task is intended to understand the willingness to use shared modes as a last-mile enabler for metro trips. In addition, it also allows the analysis of perception towards shared modes in comparison with other egress modes (*i.e.. bus/tram and walking*). For the remainder of this paper, this choice task is called *egress mode choice*.

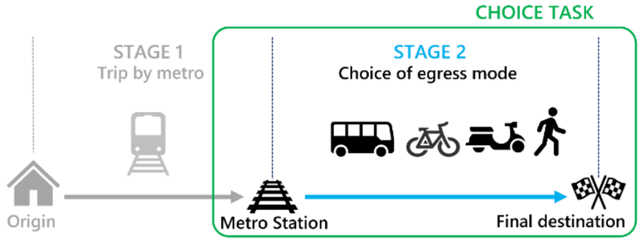


Figure 1. Choice task explanation: Egress mode choice

The second transport mode decision (step 2), assumes the overarching mode choice situation before deciding whether or not to travel by train. In this case, the whole trip chain is considered (see Figure 2). The alternative chosen in the egress mode task will represent a multimodal option together with the metro (it is already known that is the preferred combination for the respondent). The other options presented are unimodal alternatives against which such a multimodal alternative competes. This choice task aims to capture the improvement (*if any*) that the presence of shared modes integrated with metro, can represent for the attractiveness of the latter. By understanding such a relationship, it is argued that some of the potentials of the integration between PT and shared modes might be evaluated. Furthermore, it also allows to estimate competition of metro and shared modes, as shared modes can be included as separate alternatives for the whole trip, hence analysing overall preferences of modes for long-distance trips. For the remainder of this paper, this choice situation is called *complete trip mode choice*.

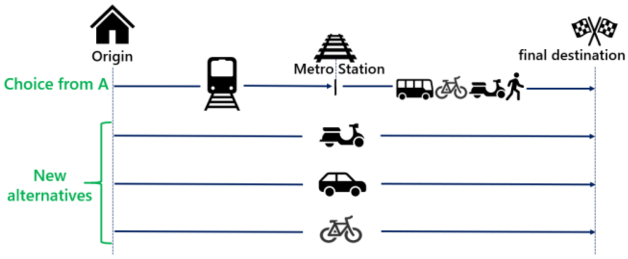


Figure 2. Choice task explanation: Complete trip mode choice

Considering the modes of interest in this study, the investigated modes are *car, bike, metro, tram/bus, shared bicycle and shared moped*. Even though the choice set still seems rather large, the characteristics of each mode make each of them available and suitable for a certain type of trip rather than for all of them. The modes available within each of the tasks described before are presented in Table 1 below. It is important to clarify that choice sets are subject to the availability of modes for respondents, as well as their ability to drive/use specific modes. For instance, if a respondent does not have a valid driving license, car and e-moped alternatives are not displayed.

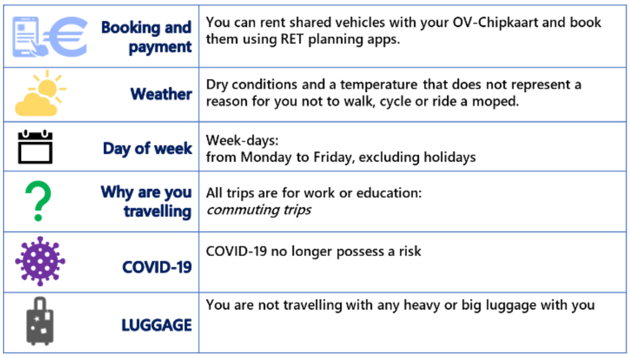
Table 1. Alternatives per choice task

Mode / Choice situation	**Egress mode choice**	**Complete trip**
Metro (multimodal)		**X**
Bus/tram	**X**	
Walk	**X**	
Bike		**X**
Car		**X**
Shared bicycle	**X**	
Shared moped	**X**	**X**

Choice context

Remember that as mentioned before, this study is developed under a hypothetical scenario in which shared modes and public transport are perfectly integrated. In addition, some other factors are defined to characterise the context of the experiment. This context represents the assumptions under which choices are made. The factors that are defined to characterise it are *Trip purpose, user-friendliness, parking availability, shared modes scheme, day of the week, COVID-19, luggage*, and *weather*. Every respondent faces a single context that is kept fixed for all scenarios. While most factors are equal for all respondents, the trip purpose is varied randomly across the sample. For simplification, it is decided to include it only making a distinction between *commuter* and *non-commuter* trips. An example of a choice context is presented in Table 2.

Table 2. Example of choice context (Commuter trip)



Booking and payment	You can rent shared vehicles with your OV-Chipkaart and book them using RET planning apps.
Weather	Dry conditions and a temperature that does not represent a reason for you not to walk, cycle or ride a moped.
Day of week	Week-days: from Monday to Friday, excluding holidays
Why are you travelling	All trips are for work or education: *commuting trips*
COVID-19	COVID-19 no longer possess a risk
LUGGAGE	You are not travelling with any heavy or big luggage with you

In addition to the context, also the attributes need to be defined. They represent the characteristic of the trip depending on the properties of each mode. The attributes included in this paper are based on different studies: (Arendsen, 2019; Arentze & Molin, 2013; Limburg, 2021; van Kuijk et al., 2021), and on the objectives and scope of this project. The overview of the attributes included per alternative in tasks of egress and complete trip mode choice are presented in Table 3 and Table 4 respectively.

Table 3. Attributes per alternative – Egress mode choice

Attributes / Alternatives	Bus/Tram	Shared bike	Shared moped	Walking
Waiting Time	X			
In-vehicle time	X	X	X	
Walking time	X			X
Searching time			X	
Travel cost		X	X	

Table 4. Attributes per alternative – Complete trip mode choice

Attributes / Alternatives	Multimodal trip		Bike	Shared moped	Car
	Metro	Egress			
Waiting Time	X				
In-vehicle time	X	*(see Table 3)*[1]	X	X	X
Walking time					X
Searching time				X	
Travel cost	X			X	X
Parking Cost					X

Every respondent faces 9 choice situations, each with the two choice tasks previously explained. Figure 3 and Figure 4 present examples of how each choice task looks in the experiment.


A. Assume you made the following trip by metro

Which of the following options would you choose to reach your destination from the metro station?

Figure 3. Example egress mode choice in Survey

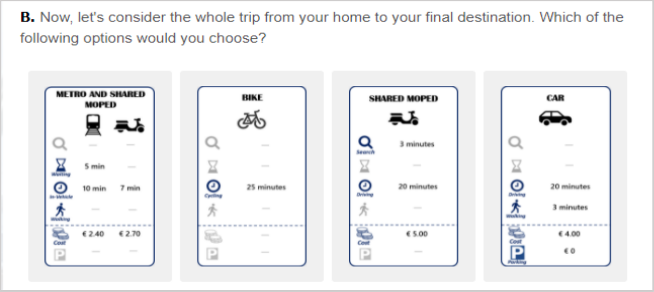

B. Now, let's consider the whole trip from your home to your final destination. Which of the following options would you choose?

Figure 4. Example complete trip mode choice in Survey

Attribute levels

Attribute Levels are determined considering different OD combinations within the Rotterdam region and computing respective attributes per each alternative for each of those trips. To determine travel times, the most popular trip-planning apps are used: *Google Maps* (*Google Maps*, 2021), *9292* (9292, 2021) and *RET planner app* (*Optimaal OV - RET*, 2021). Regarding costs, information available in the webpages of RET and shared mobility providers is used as a basis (*Check.*, 2021; *Felyx - Beat the Streets*, 2021; *Optimaal OV - RET*, 2021; Donkey Republic, n.d.; GO Sharing, 2021; Mobike, 2021; OV-fiets, 2021). The main idea behind the approach adopted is to obtain realistic values for the case at hand. To estimate the impact of possible pricing schemes and policies, the range of attributes is expanded beyond the range of current values. Table 5 provides an overview of the attribute levels varied for the egress mode choice, while Table 6 presents the ones associated with the complete trip.

Table 5. Attribute levels – Egress mode choice

Attribute / Alternative	Bus / Tram	Shared bicycle	Shared moped	Walking
Waiting time (min)	2, 5, 8	-	-	-
In-vehicle time (min)	5, 7, 9	7, 10, 13	5, 7, 9	-
Walking time (min)	1, 3, 5	-	-	12, 16, 20
Cost (€)	1.2, 1.7, 2.2	1.2, 1.7, 2.2	1.7, 2.2, 2.7	-

Table 6. Attribute levels – Complete trip mode choice

Attribute / Alternative	Metro*	Bike	Shared moped	Car
Waiting time (min)	1, 3, 5	-	-	-
In-vehicle time (min)	10, 15, 20	20, 25, 30	15, 20, 25	20, 25, 30
Walking time (min)	-	-	-	1, 3, 5
Searching time (min)	-	-	1, 3, 5	-
Travel cost (€)	1.8, 2.4, 3	-	4, 5, 6	2, 4, 6
Parking Cost (€)	-	-	-	0, 5, 10

* In addition to the attributes of the metro, this option also includes attributes of the selected egress mode.

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[1] The attributes included in the egress part of the multimodal trip alternative depend on the choice made for the egress leg

3 SURVEY AND SAMPLE

The survey was designed using the online tool *Qualtrics*. The largest part of the survey is the questionnaire constructed from the determined experimental designs (*SC experiment*). In addition, it also includes an introductory section, questions regarding the respondents' socio-demographics and transport-related questions. The outline of the survey is presented in Figure 5.

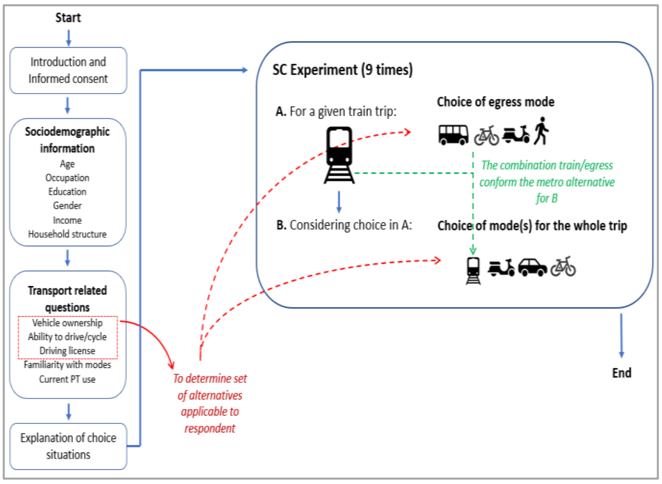

Figure 5. Survey outline

The distribution is performed using an online panel: *Qualtrics*, and the sample is limited to people living in Rotterdam. The survey was accessed by 625 people, of which 525 were completed. The sample was then filtered based on the total response time and variability of the answers given. After the process, a total of 487 responses were considered valid.

Table 7 presents the composition of the sample in function of sociodemographic characteristics. As mentioned before, the sample is conformed only by inhabitants of Rotterdam. Accordingly, its composition is compared to the one of the city, using official statistics available in (Centraal Bureau voor de Statistiek, 2021).

Table 7. Socio-demographic characteristics of the sample

Characteristic	Categories	Sample	Rotterdam (CBS, 2020)
Gender	Male	41%	49%
	Female	59%	51%
	Prefer not to say	0%	-
Age	18-25	7%	15%
	26-35	18%	21%
	36-45	17%	16%
	46-55	16%	16%
	56-65	21%	14%
	66-75	16%	10%
	>75	4%	8%
	Prefer not to say	0%	-
Education	VMBO (MAVO)	15%	12%
	HAVO/ VWO / MBO	42%	45%
	Bachelor	24%	21%
	Master	13%	12%
	Other	4%	9%
	Prefer not to say	1%	-
Household	1 person	33%	48%
	2 people	40%	
	3 people	11%	52%
	> 3 people	15%	
Income	< €10.000	4%	14%
	€10.000 - €30.000	28%	37%
	€30.000 - €50.000	26%	23%
	€50.000 - €100.000	19%	21%
	€100.000 - €200.000	2%	4%
	> €200.000	0%	1%
	Prefer not to say	20%	-

To be able to interpret the results properly, it is important to first understand the characteristics of the respondents concerning their use of the different transport modes as well as their awareness of shared alternatives. This transport-related information is depicted in Table 8. As it can be observed, nearly three-quarters of the sample travel either two or fewer days a week by PT. In terms of familiarity with shared modes, over 20% of the sample are not familiar at all with either shared modes or shared moped, which strikes as surprising considering the number of vehicles and operators available within the city. Nonetheless, similar studies have also found high percentages of unfamiliarity with shared bicycles and shared mopeds. For instance, in a study of the potential use of on-demand services for urban mobility within the Netherlands, Geržinič et al. (2021) report that 17% of the participants in their survey had never heard of shared bicycles/mopeds. Arendsen (2019) on the other hand reports that 14% of the sample of his study had never heard of shared bicycles. Regarding the use of shared modes, 80% of participants in this study claimed having never used either a shared bicycle or a shared moped. This figure is in between of those found in Arendsen (2019) and Geržinič et al. (2021), which found values in this regard of 72% and 90% respectively. Note however that the former explicitly refers to previous use of shared bicycles, as shared mopeds were not included in the study.

Table 8. Transport-related characteristics of the sample

Characteristic	Categories	%
Frequency of use of public transport	< 1 day a week	45%
	1-2 days a week	28%
	3-4 days a week	15%
	>= 5 days a week	10%
	Prefer not to say	2%
Familiarity with shared modes	Familiar with shared bikes and shared mopeds	63%
	Only familiar with shared bikes	5%
	Only familiar with shared mopeds	9%
	Not familiar with either shared mode	22%
	Prefer not to say	1%
Previous use of shared bicycles or shared mopeds	Yes	19%
	No	81%
	Prefer not to say	0%
Ability to ride a bicycle	Yes	89%
	No	10%
	Prefer not to say	1%
Bicycle availability	Yes	77%
	No	22%
	Prefer not to say	1%
Possession of valid driving license	For car and motorcycle	17%
	Only for car	61%
	Only for motorcycle	1%
	Neither	21%
	Prefer not to say	0%
Car availability	Yes	71%
	No	29%
	Prefer not to say	0%

4 CHOICE OVERVIEW

Before proceeding to the discrete choice model estimation, it is important to do a general examination of their choices. By doing this, some mode preferences can be already noticed. Note however that in this part of the data analysis, the effects of the variation of attributes among transport modes are not considered. Despite aiming for an experiment with choice situations as close as possible to real-life, that is not always possible. Hence, for some scenarios, the variation of attributes might have played a very important role in choices, which is not yet captured in this overview. In Figure 6 an outline of the preferences exhibited for the egress mode choice is presented. It is observed a clear tendency towards walking and PT, being the latter in this case represented by the bus/tram option. Nevertheless, shared modes account for a quarter of the total of choices for egress mode, which might be argued to suggest a certain potential of these modes to cover the last mile of multimodal trips with metro as the main mode.

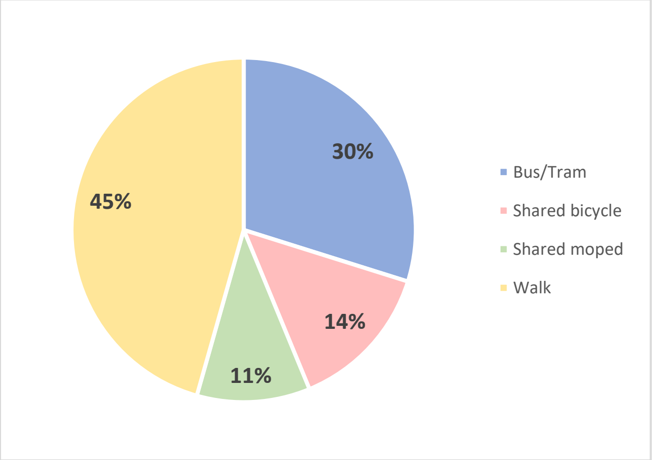

Figure 6. Choice overview – Egress mode choice

Figure 7 presents an outline of the preferences exhibited for the complete trip mode choice. As noticed, half of the choices are for privately owned vehicles (*i.e. car and bike*), whereas the other half is distributed between metro combinations and shared mopeds. It strikes as interesting the high shared of metro trips, especially considering the rather low proportion of frequent PT travellers within the sample. Besides, by being chosen almost once for every ten tasks, shared mopeds seem to be an alternative for long-distance trips, and not only for short trips (including access and egress to and from PT respectively). Note that the distribution of egress modes when metro is chosen varies compared to the overall distribution presented in Figure 6. According to the results, metro seems to be chosen more often for the complete trip when it is combined with bus/tram as egress mode, rather than when egress is done walking. Furthermore, the proportion of shared modes as egress alternatives decreases compared to the overall distribution. The latter could be influenced by potential strong preferences towards PT of some respondents (‘*PT-lovers*’).

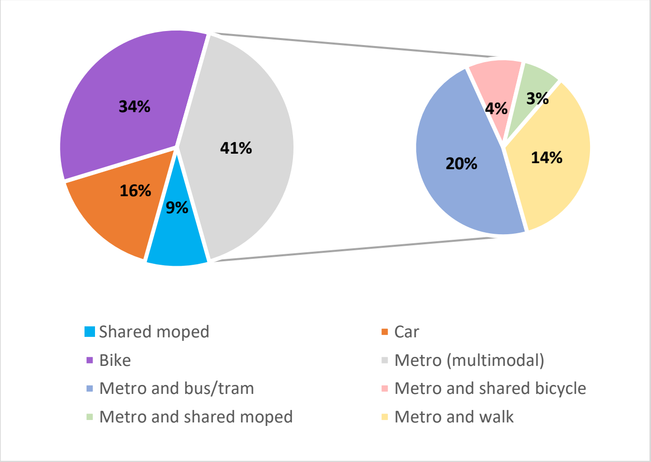

Figure 7. Choice Overview – Complete trip mode choice

5 MODEL SPECIFICATION AND ESTIMATION

Two types of models are included in the study: Multinomial logit (MNL) and mixed logit (ML). For each of them, different models are estimated, each with specific aims that are further described in the remainder of this section. The estimation of the models is performed using *PandasBiogeme*, an open-source *Python* package specialised in the computation of discrete choice models (Bierlaire, 2020). It is important to mention that all models are developed for the complete trip. By doing this, both choices per scenario (*i.e. egress mode choice* and *complete trip mode choice*) are included in one single model.

All models estimated are based on the concept of *Random Utility maximisation*, which in short assumes that the preferences of decision-makers are driven by the numeric evaluation of each alternative, from which the best evaluated is chosen. The evaluation of each alternative is defined by its attributes, which added return a value, called *utility*. However, the decision-maker does not have perfect discrimination capability. Thus it is assumed to have incomplete information, and consequently, uncertainty also plays a role (Ben-Akiva & Bierlaire, 2000). Accordingly, the utility of an alternative *i*, for a decision-maker *n* (U_{in}) is defined as:

$$U_{in} = V_i + \varepsilon_{in} \tag{1}$$

Where V_i is the systematic utility and ε_{in} the error term. The systematic part of the utility is related to its observed attributes, whereas the error term includes everything else influencing an individual’s choice, like for instance unobserved factors, heterogeneity amongst individuals, *etc.*(Van Oort, 2019). The systematic utility is defined as

$$V_i = \sum_m \beta_m \times x_{im} \tag{2}$$

In the equation: β_m represents the relative importance of attribute *m*, and x_{im} the numerical value of alternative *i* for the respective attribute *m*. According to the RUM model, an alternative *i* is chosen by a decision-maker *n* if its utility U_{in} is greater than that of all other alternatives *j*, as expressed by

$$U_{in} > U_{jn}, \forall j \neq i \tag{3}$$

How the utility defines the probability of an alternative being chosen is defined by the type of discrete choice model applied. The different models are defined according to how they deal with the random part of the utility. The most widely used discrete choice model is the Multinomial logit model (MNL). It assumes that the random part of the utilities are independently and identically Gumbel distributed (IID) (Ben-Akiva & Bierlaire, 2000). As a result, the error terms of different alternatives are uncorrelated. According to the model formulation, the probability of an alternative i being chosen from a set of alternatives C can be expressed as (Ortuzar & Willumsen, 2011):

$$P_i = \frac{\exp(\beta\ V_i)}{\sum_{j \in C} \exp(\beta\ V_j)} \tag{4}$$

The relationship of the probabilities of any two alternatives does not depend on the choice set but on their own utilities. Hence, they are unaffected by the systematic utilities of other alternatives (Ben-Akiva & Bierlaire, 2000). Consequently, it ignores correlations that might exist between the non-systematic part of the utility of some alternatives (Van Oort, 2019). To deal with that shortcoming, other approaches have emerged. For instance, the Mixed logit model (ML). This model can be seen as a generalisation of the MNL, and it is recognised by its ability to capture three things that the standard MNL approach cannot: Nesting of alternatives, parameter heterogeneity and panel effects (Van Oort, 2019). It does so by allowing the addition of random parameter variation, unrestricted substitution patterns and correlation in unobserved factors of observations during time (Train, 2002).

ML is based on its choice probabilities, which are the integral of logit probabilities $L_i(\beta)$(see equation 4) over a density of parameters $f(\beta)$(Train, 2002). It can be expressed as it follows:

$$P_i = \int L_i(\beta) f(\beta) d\beta \tag{5}$$

5.1 MNL Model

The starting point is the estimation of a base MNL model, which is the base from which all other models are derived. To illustrate the parameters included, and how they are related to the different variables that characterise the alternatives, the utility functions for all modes are presented in equations 6-12 (the specification of each symbol included in the equations is presented in Table 9). Note that as ASC parameters are defined per each separate mode, multimodal options (e.g. metro and shared bike combination) have two ASC involved in their utilities. Although most of the parameters are generic, some are only applicable to a certain mode. Considering the outcomes of Arentze & Molin (2013), previously used to define the priors, a distinction is made between time and cost parameters for main and egress legs.

$$\begin{aligned} U_{metro\&bt} = {} & ASC_{metro} + ASC_{bt} + \beta_{metroWait} * wt_{metro} + \beta_{mainTime} * vt_{metro} \\ & + \beta_{mainCost} * cost_{metro} + \beta_{egressTime} * (vt_{bt} + wt_{bt}) \\ & + \beta_{walk} * walk_{bt} + \beta_{egressCost} * cost_{bt} \end{aligned} \tag{6}$$

$$\begin{aligned} U_{metro\&sb} = {} & \mathrm{ASC}_{\mathrm{metro}} + \mathrm{ASC}_{\mathrm{sb}} + \beta_{\mathrm{metroWait}} * \mathrm{wt}_{\mathrm{metro}} + \beta_{\mathrm{mainTime}} * \mathrm{vt}_{\mathrm{metro}} \\ & + \beta_{\mathrm{mainCost}} * \mathrm{cost}_{\mathrm{metro}} + \beta_{\mathrm{egressTime}} * \mathrm{vt}_{\mathrm{sb}} + \beta_{\mathrm{egressCost}} \\ & * \mathrm{cost}_{\mathrm{sb}} + \varepsilon \end{aligned} \tag{7}$$

$$\begin{aligned} U_{metro\&sm} = {} & ASC_{metro} + ASC_{smE} + \beta_{\mathrm{metroWait}} * wt_{metro} + \beta_{\mathrm{mainTime}} * vt_{metro} \\ & + \beta_{\mathrm{mainCost}} * cost_{metro} + \beta_{\mathrm{egressTime}} * vt_{smE} + \beta_{\mathrm{egressCost}} \\ & * cost_{smE} + \varepsilon \end{aligned} \tag{8}$$

$$\begin{aligned} U_{metro} = {} & ASC_{metro} + \beta_{metroWait} * wt_{metro} + \beta_{mainTime} * vt_{metro} + \beta_{mainCost} \\ & * cost_{metro} + \beta_{walk} * walk_{metro} + \varepsilon \end{aligned} \tag{9}$$

$$\begin{aligned} U_{sm} = {} & ASC_{sm} + \beta_{walk} * st_{sm} + \beta_{mainTime} * vt_{sm} + \beta_{mainCost} * cost_{sm} \\ & + \varepsilon \end{aligned} \tag{10}$$

$$\begin{aligned} U_{car} = {} & ASC_{car} + \beta_{walk} * wt_{car} + \beta_{mainTime} * vt_{car} + \beta_{mainCost} \\ & * (cost_{car} + parking) + \varepsilon \end{aligned} \tag{11}$$

$$U_{bike} = ASC_{bike} + \beta_{mainTime} * vt_{bike} + \varepsilon \tag{12}$$

Table 9. Description of symbols

Symbol	Description
$U_{metro\&bt}$	Utility of metro and bus/tram alternative
$U_{metro\&sb}$	Utility of metro and shared bicycle alternative
$U_{metro\&sm}$	Utility of metro and shared moped alternative
U_{metro}	Utility of metro alternative
U_{sm}	Utility of shared moped alternative
U_{car}	Utility of car alternative
U_{bike}	Utility of bicycle alternative
ASC_{metro}	Alternative specific constant for metro
ASC_{bt}	Alternative specific constant for bus/tram
ASC_{sb}	Alternative specific constant for shared bicycle
ASC_{smE}	Alternative specific constant for shared moped as egress mode
ASC_{sm}	Alternative specific constant for shared moped as main mode
ASC_{car}	Alternative specific constant for car
ASC_{bike}	Alternative specific constant for bike
$\beta_{metroWait}$	Parameter for waiting time for metro
$\beta_{mainTime}$	Parameter for in-vehicle time in main mode
$\beta_{mainCost}$	Parameter for cost of main mode
$\beta_{egressTime}$	Parameter for in-vehicle time in egress mode
β_{walk}	Parameter for walking time
$\beta_{egressCost}$	Parameter for cost of egress mode
wt_{metro}	Waiting time for metro
vt_i	In vehicle time in mode *i*
$cost_i$	Cost of mode *i*
wt_i	Waiting time for mode *i*
$parking$	Parking cost for car
ε	Random component of the utility

Results

In addition to the base MNL model, MNL models with interaction effects were also estimated. In these models, socio-demographic and transport-related information were included. Interactions were evaluated with time, cost and ASC parameters separately, being the last the one that yielded the most significant results. An overview of modal fit indicators of the best fitting models is presented in Table 10.

Table 10. Modal fit indicators – MNL

	Initial log-likelihood	Final log-likelihood	Rho-square
MNL Base	-7607.93	-6313.44	0.170
MNL Age	-7607.93	-6180.694	0.188
MNL PT-use	-7494.61	-6120.10	0.183
MNL Previous use of shared modes	-7591.81	-6248.0	0.177

It is observed that including interaction effects with *age* and *frequency of use of public transport* seems to produce the highest improvement of model fit indicators. As mentioned before, the most significant results are associated with interaction with ASC parameters. The results interactions of age and public transport use with ASC are presented in of these two model can be better visualized in

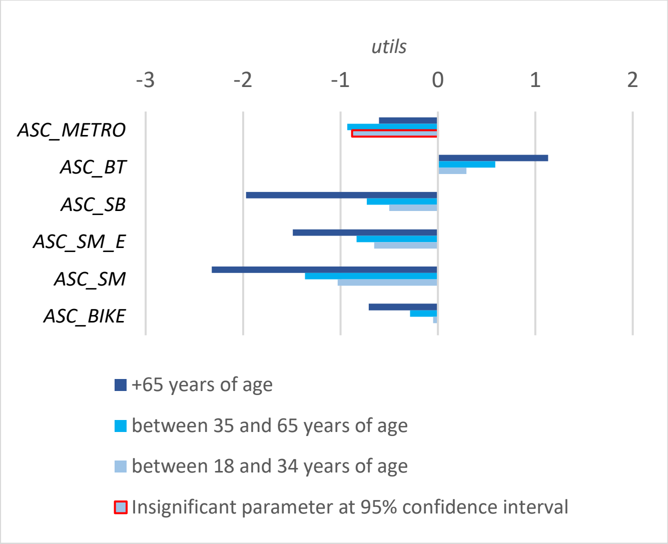

Figure 8. Age effects on ASC

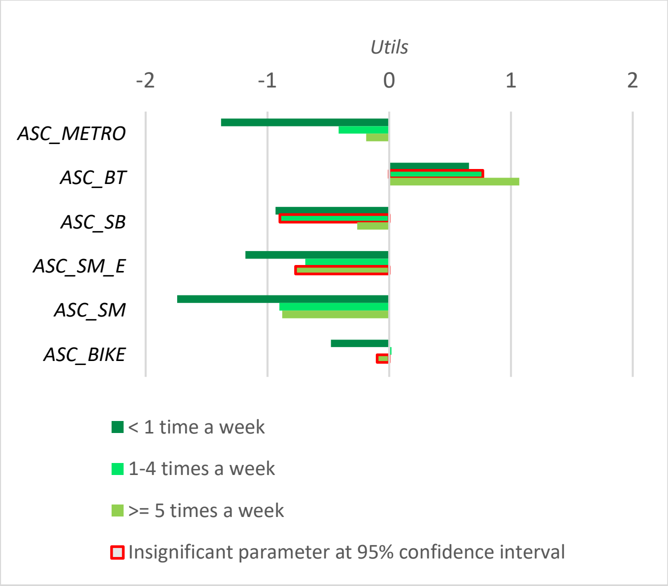

Figure 9. Frequency of use of PT effects in ASC

In Figure 8 it can be noticed that the younger the group, the higher the base preference towards shared alternatives both as egress (*shared bicycle* and *shared moped*) and as main mode (*shared moped*). Hence, the results of this study suggest that young socio-demographic groups might be more likely to adopt shared modes as part of their mobility behaviour. The latter is not surprising, considering that previous studies such as (Van Kuijk et al., 2021) had already highlighted this tendency of younger people to be more likely to use shared modes than older people. Regarding the frequency of use of PT, it is found that that perception towards shared modes is positively affected by the frequency of use of PT. It is important to mention that these results go in line with the ones obtained in (Zhang & Zhang, 2018), which found a significant positive relationship between the frequency of PT use and the frequency of bike-sharing use.

5.2 ML Model

As mentioned in 5.1, the ML formulation is based on the MNL base model. Models are estimated to study nesting effects and taste heterogeneity, both including panel effects. According to the goal of this study, the most relevant results are found for taste heterogeneity. Taste heterogeneity is evaluated in two parts: the first part evaluates heterogeneity in cost and time parameters, and the second part evaluates heterogeneity in ASC parameters. Table 11 presents the overview of modal fit indicators of these two models along with those of the base MNL model.

Table 11. Modal fit indicators ML

	Initial log-likelihood	**Final log-likelihood**	**Rho-square**
MNL Base	-7607.93	-6313.44	0.170
ML heterogeneity in time and cost parameters	-7607.93	-5316.04	0.301
ML heterogeneity in ASC	-7607.93	-4642.00	0.390

Note that in general assuming parameters to be randomly distributed yields considerably better modal fit indicators than the ones obtained with the base MNL model. Since it is the best fitting model, only the complete results of the ML model to capture heterogeneity in ASC parameters are presented (see Table 12). However, the results of taste heterogeneity for time and cost parameters are also discussed. In general, the results suggest that cost parameters are rather widely distributed across the population. In other words, while for some people the cost of the trip is a very relevant determinant of their choice of mode, for others its effect is more limited. Because of this, alternatives with similar cost characteristics are expected to be correlated. Concerning time parameters, it is interesting to see that the distribution of the taste for travel time in the main mode is rather tight. Accordingly, the results suggest that sensitivity for this characteristic of a trip does not seem to vary considerably amongst respondents. As it can be noticed in Table 12, some new parameters are added to the base formulation presented in 5.1: *SIGMA* parameters. They are indicators of the variance of the ASC associated with them.

Table 12. Model results – ML to capture ASC heterogeneity (** parameter significant at a 95% confidence interval)

Parameter	**Value**	**Rob. SE**	**Rob. t-test**
ASC_BIKE	-0.561	0.284	-1.97*
ASC_BT	0.373	0.361	1.03
ASC_METRO	-1.07	0.339	-3.15**
ASC_SB	-1.89	0.426	-4.43**
ASC_SM	-1.7	0.202	-8.43**
ASC_SM_E	-2.19	0.499	-4.39**
B_EGRESS_COST	-0.715	0.112	-6.37**
B_EGRESS_TIME	-0.0734	0.0167	-4.4**

B_MAIN_COST	-0.186	0.0191	-9.74**
B_MAIN_TIME	-0.0711	0.00803	-8.85**
B_METRO_WAIT	-0.0307	0.0324	-0.947
B_WALK	-0.11	0.0137	-7.98**
SIGMA_BIKE	3.02	0.247	12.2**
SIGMA_BT	2.36	0.171	13.8**
SIGMA_CAR	2.45	0.197	12.4**
SIGMA_METRO	2.37	0.169	14.1**
SIGMA_SB	-2.09	0.183	-11.4**
SIGMA_SM_E	-2.36	0.286	-8.27**

** *parameter significant at a 99% confidence interval,*
* *parameter significant at a 95% confidence interval*

Consistent with previous models, the mean ASC are all negative, which suggests an intrinsic preference towards the car that is not explained by the other parameters included in the model. However, since in this case the parameters are distributed, there is a certain probability of an individual having a preference towards one (or more) modes over that of the car. *ASC_SM* is fixed to its mean value, since in a preliminary model estimation it showed to have the lowest variance. Note that the distributions of *ASC_CAR* and *ASC_BT* are very close to one another. However, it is important to take into account that this does not mean that the base preference of the modes is the same across the population, only that their distributions are very similar. According to the estimates, it is noticed that all parameters are rather widely distributed, which suggests high variation in the perception towards different modes across the population. As discussed in 5.1, some of this variation might be explained by the effects of socio-demographic and transport-related characteristics.

6 CONCLUSIONS

Considering what is discussed in this paper, it can be concluded that the integration of public transport and shared modes can affect mode choice within the urban environment in multiple ways. On the one hand, shared modes seem to be appealing alternatives as egress modes for metro trips on a considerable amount of occasions. This can be attributed to a variety of factors, which following what has been already discussed in previous studies might include their flexibility, their ability to provide better accessibility to certain areas, or their rather high speeds, among others. Considering that satisfaction with public transport is affected by the whole door-to-door trip (Susilo & Cats, 2014), this might positively influence preference towards transit services. Hence, by becoming attractive alternatives for last-mile connections, shared modes can be argued to serve indeed as a complement for the metro. In addition, shared mopeds proved to be an interesting alternative as an individual mode for long-distance trips, which in a way might support the idea of them being simultaneously complementary and competition to public transport, highlighted previously by Ricci (2015).

Five main aspects appear as important determinants of choices under the assumed conditions: *total travel time, egress cost, having used shared modes before, age,* and *frequency of use of public transport.* First, regarding time, travellers seem to be similarly sensitive to time in the main leg (metro), and in the last-mile (shared mode), so improving total travel time might be beneficial, even if does so by reducing time in metro and increasing the one in shared modes. In other words, travellers seem to be willing to travel longer in their '*last-mile*', if it results in shorter overall travel times. Secondly, concerning cost, the cost of shared modes as egress alternatives might be a strong disincentive against its use. If transport operators want to increase the share of multimodal trips involving transit and shared modes, pricing schemes should be thought carefully as not to link high costs to the egress leg in specific.

Thirdly, the results of this study suggest a clear positive attitude towards shared modes of those who have used them before. Accordingly, it seems reasonable to think that encouraging a first experience with shared modes, can positively influence the overall perception of users towards these modes. Finally, young people and frequent public transport users showed considerably better perceptions about shared modes than their counterparts. Accordingly, it might be interesting to design strategies to specifically target these groups.

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Studying mode choice in multimodal networks including shared modes

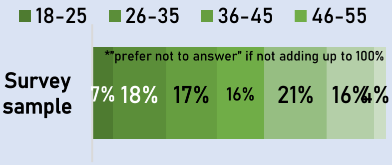
A case study for the city of Rotterdam – Alejandro Montes Rojas – TU Delft

Survey

625 individuals living in Rotterdam

59% female
41% male

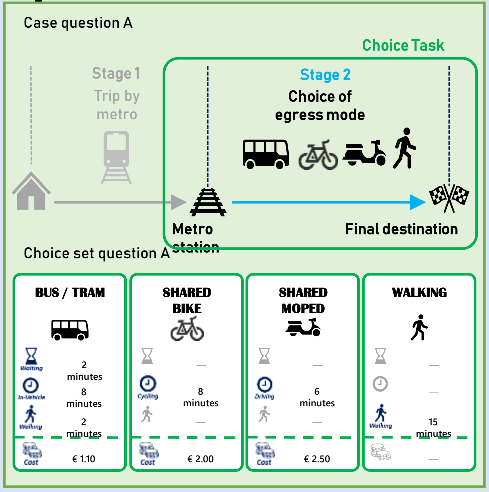
Age



81% hadn't used a shared mode before

Questions

Stated preference survey, consisting of two consecutive question types:


Case question A

Choice Task

Stage 1
Trip by metro

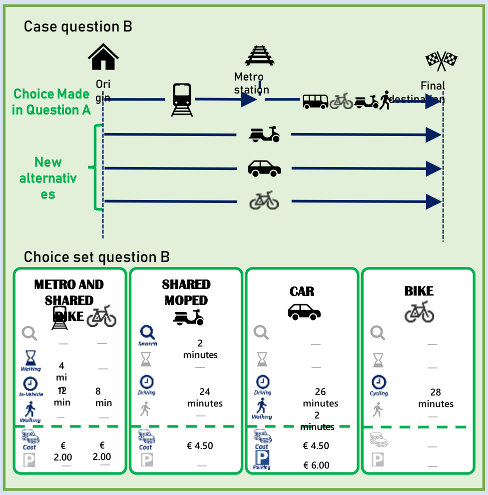
Stage 2
Choice of egress mode

Metro station

Final destination

Choice set question A

BUS / TRAM	SHARED BIKE	SHARED MOPED	WALKING
Waiting: 2 minutes	—	—	—
In-Vehicle: 8 minutes	Cycling: 8 minutes	Driving: 6 minutes	—
Walking: 2 minutes	—	—	Walking: 15 minutes
Cost: € 1.10	Cost: € 2.00	Cost: € 2.50	—


Case question B

Choice Made in Question A

Origin

Metro station

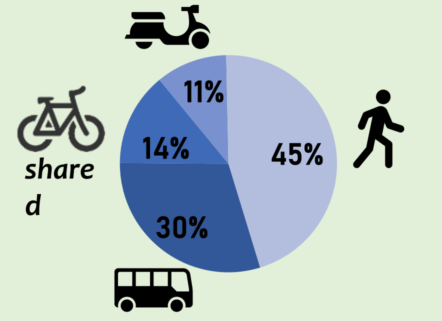
Final destination

New alternatives

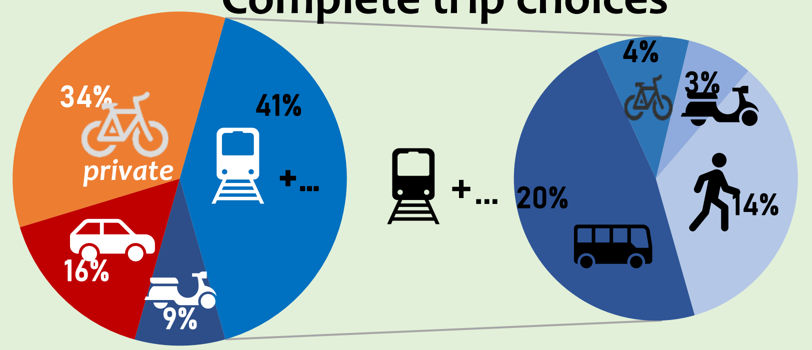
Choice set question B

METRO AND SHARED BIKE		SHARED MOPED	CAR	BIKE
—	—	Search: 2 minutes	—	—
Waiting: 4 mi	—	—	—	—
In-Vehicle: 12 min	8 min	Driving: 24 minutes	Driving: 26 minutes	Cycling: 28 minutes
Walking: —	—	—	Walking: 2 minutes	—
Cost: € 2.00	€ 2.00	Cost: € 4.50	Cost: € 4.50	—
—	—	—	Parking: € 6.00	—

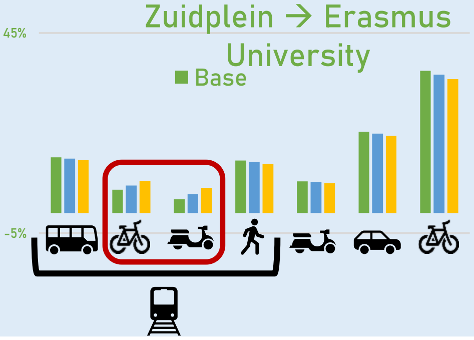
Egress choices



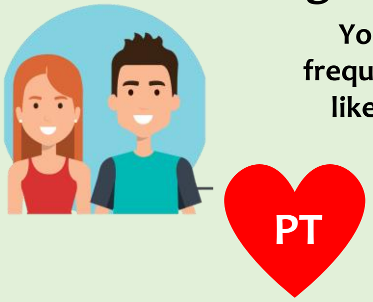
Complete trip choices



Evaluating price reduction of shared modes as egress for two hypothetical trips



Some interesting insights!



Young people and frequent PT users more likely to use shared modes!

Previous shared modes users have better perception about them!

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Contents

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PART II. DATA COLLECTION AND ANALYSIS

PART III. CONCLUSION

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List of Figures

List of Abbreviations

PT: Public Transport
SM: Shared Modes
SC: Stated Choice
SP: Stated preference
RP: Revealed preference
MNL: Multinomial logit model
NL: Nested logit model
ML: Mixed logit model

PART I:

Introduction and approach

1 Introduction

In the present chapter it is given an introduction to the project. It includes some background information, the problem that is addressed and the relevance of doing so. In addition, an overall outline of the structure of the project and the report is presented.

1.1 Background

Climate change, together with many other environmental challenges, have brought with them, the need for a more sustainable society. As such, a balanced development comprising social, economic and environmental concerns is needed (*United Nations*, 2021). The transport sector is closely related to that challenge. According to the United Nations, by 2018 more than 50% of the global population lived in cities. An important part of living in such places is the activity performed to move between different locations, so-called "transportation" or "mobility". In developed countries, there is a considerable prevalence of motorized vehicles, which are often related to high levels of pollution and thus considered one of the main contaminating sources in urban environments (Khreis et al., 2016). As a result, public policies have been put in place in several countries to encourage the use of public transport and active modes (Otero et al., 2018). When examining the Sustainable Goal #11 of the United Nations: "Sustainable cities and communities", the need for proper planning in Public transport (PT) is explicit; according to them, making cities sustainable "involves investment in public transport, creating green public spaces, and improving urban planning and management in participatory and inclusive ways"(*United Nations*, 2021). As a response to those challenges, and with the support of emerging technologies and business models, new mobility solutions have come to the scene.

One example is what is known as 'micro-mobility'. It includes small human and electric-powered vehicles, such as bicycles, e-bikes and standing scooters-also known as e-scooters- (Oeschger et al., 2020). Different systems have emerged in which this kind of vehicles are provided to the public in the form of short-term rental schemes. Such systems are usually either dock-less (also known as free-floating) or station-based. The former refers to those cases in which the vehicles can be found and left at many random locations around the city, depending on your own needs and the use of them made by previous travellers. Station-based schemes, on the other hand, represent systems in which vehicles must be rented and given back at specific locations acting as stations. In those systems using motorized vehicles, they are usually electric-powered. In addition to micro-mobility solutions, 'scooter-sharing' and 'car-sharing' are also earning their places in the mobility market. The former refers to a type of scooter in which the driver (and possibly an extra passenger) are seated, also known as moped. In order to avoid confusion with standing scooters, in the remainder of this report, they will be referred to as shared mopeds. Systems of car-sharing and moped-sharing are both based on the principle of making use of a single vehicle, by multiple users on a ‘per trip basis’ (Ferrero et al., 2018). Similar to micro-mobility, these systems can be either free-floating or station-based, and the fleets in charge of them are mainly electric-powered. The bundle of the different systems mentioned is commonly called shared modes or shared mobility (SM). They are differentiated mainly by the type of vehicles, the price related to them, and the rental conditions, sometimes limited by age and the availability of valid driving licenses. In Figure 1 some examples of these previously mentioned shared modes are presented. It is important to mention that there is no total agreement in literature with regard to which modalities can be considered part of shared mobility and which not. In general, ride sharing (*e.g. car-pooling*) and ride hailing (*e.g. uber*) services are usually also considered shared modes.

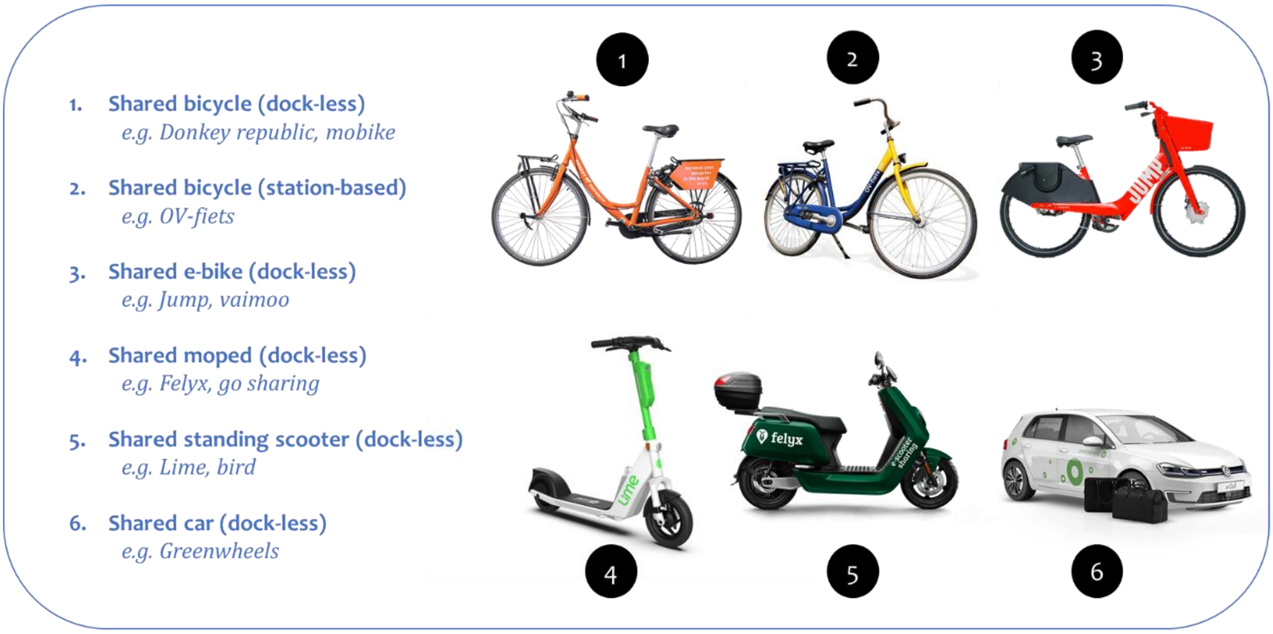

Figure 1. Examples of different shared modes

As a result of the emergence of these new transport modes, along with private vehicles (e.g. cars, bicycles, motorcycles) and traditional Public Transport (e.g. metro, tram, bus), a great number of shared vehicles can now also be found in several cities across the world. Several shared mobility providers (both private and public) have surfaced, which for instance in The Netherlands include: *OV-fiets, mobike, Donkey Republic, Felyx, GO Sharing, check*, among others. Consider that in addition to the appearance of SM, new types of collaboration between transport operators have also emerged. An example of this is the concept of Mobility as a Service (MaaS), which represents the integration of new mobility services (e.g. bicycle/scooter sharing, ride-sharing, car pooling, etc) with traditional modes (e.g. PT, taxi, etc) in a single platform. These platforms allow the planning, booking, and payment through a unique service provider, which in this case is known as MaaS provider (Jittrapirom et al., 2017; Mulley et al., 2018; Polydoropoulou et al., 2020).

Under these circumstances, new challenges have appeared for transport authorities and public transport (PT) operators, who need to somehow react to the appearance of these new mobility trends. Taking the position of PT operators, several decisions need to be made. For instance, they need to decide whether to collaborate with the providers of shared mobility services to offer integrated alternatives and if so, how the collaboration should be. Furthermore, they might wonder whether they should or not adopt these MaaS platforms to collaborate with SM providers. In case they do, they could also ask themselves if they should join existing platforms or develop their own. Moreover, it would be reasonable to ponder about offering their own shared services, as some PT providers have already decided to do, take as example TfL in London, or NS and HTM in the Netherlands.

In order for public transport operators to design and judge their reaction strategies properly, it is important to first understand how the different transport modalities interrelate. At the moment, it is still unclear which are the effects for them of the appearance of these new transport means. On the one hand, SM can compete with Public transport modes, and as such decrease their ridership. But on the other hand, they can also complement each other. Accordingly, and as a result of a large number of shared mobility alternatives that have emerged in Rotterdam and neighbouring areas, RET as PT operator in these areas is interested in studying the current (and also the potential) synergies between SM and its PT services. At the moment, they are working closely with transport authorities and with other mobility providers in the area to design integrated solutions aiming for more sustainable mobility. For instance, they are working on the development of a MaaS platform, and currently, the availability of shared bicycles and mopeds from some providers can be found in their planning app.

1.2 Preliminary Literature Review

The relationship between shared modes and public transport has been widely studied in recent years. While some academics have based their studies on analysing whether shared modes are competition or complement to public transport, some others have instead studied the use of shared modes as a whole, from which they conclude its (potential) synergy with transit. The most utilised methods are surveys, stated choice experiments, and vehicle data analysis. The first two are mostly used to understand the user's perspective, whereas the latter focuses on understanding how shared modes are used. Even though conclusions vary among studies, many agree on the potential of the combination of public transport with shared modes, to achieve more sustainable mobility in urban environments (Ferrero et al., 2018; Hardt & Bogenberger, 2019; Machado et al., 2018; Meng et al., 2020; Oeschger et al., 2020).

Nonetheless, some academics argue that SM do not only complement but also compete against PT. For instance, regarding bike sharing Ricci (2015) claims that it can at the same time complement and substitute public transport. In a similar line, a study performed by Leth et al. (2017) in some North American cities suggests that the relationship, and with it, the extent to which the modes compete and complement each other vary not only amongst cities but also between different areas of a single one.

Some studies related to shared mobility and public transport have been carried out in The Netherlands. In Utrecht for example, van Kuijk et al. (2021) performed a stated choice experiment to study user preferences for shared modes as last-mile connections with public transport. Similarly, Arendsen (2019) also performed a stated choice experiment studying the use of shared modes as access or egress modes. In this case, the focus was on multimodal trips including trains. Using a case study in Delft, Ma et al. (2020) studied how different schemes of bike-sharing systems affect modal shift. In The Hague (van Marsbergen (2020) used operational trip data of shared bicycles to examine the use of this kind of system, with a focus on its combined use with public transport.

1.3 Problem definition

Following the emergence of new mobility trends, in which shared mobility plays an essential role, Public transport operators face the challenge of reacting in a convenient way to the changes brought to the transportation scene. Accordingly, they need to make numerous decisions that include amongst other things whether to collaborate or not with other mobility providers, whether to develop or not their own shared systems and in both cases how to design the integration of the different types of services. Taking as reference the cycle presented in Figure 2, it might be argued that to make said choices, they first need to understand how SM relate to PT under different conditions, and for that, they need to analyse the behaviour and preferences of users. Even though several studies have been done to tackle these mentioned needs, they have mostly focused on analysing the current use of SM and the perception of users towards the different modes. It can be argued that it is also of great importance to understand the underlying reasons that result in said use and perceptions, which are usually captured in mode choice studies. Subsequently, some studies have been performed studying mode choice involving SM and PT. However, such research has been often limited to analysing first/last mile travel. As a result, those studies have ignored the effects of SM for the overarching choice of using PT or not, as well as how they compete against each other. Including said relationships might be relevant to understand if potential modal shifts can occur as a result of an improvement in PT services due to the presence of SM, and thus if the integration of modes is potentially beneficial.

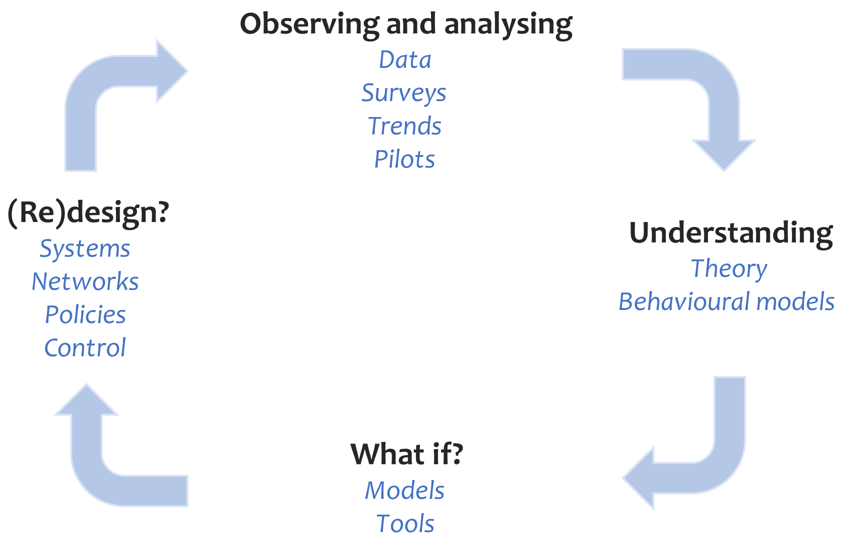

Figure 2. Research and design cycle in Public transportation. Adapted from (Van Oort, 2019)

It is important to mention that the challenges faced by PT operators are not limited to decisions regarding integration and collaboration. Depending on those choices some changes in travel behaviour are to be expected, which might result in the need to adapt the design and operation of public transport networks (*e.g. stop spacing, frequency of services, etc*).

Finally, it is important to mention that previous studies have been mainly focused on the train as PT mode, and how it can be combined with SM. However, the relationships of SM with Metro, are still to be studied.

1.4 Research Question

Following what is presented in Sections 1.1-1.3, the present research has the objective of providing Public transport operators tools and insights that allow them to make decisions regarding their reaction to the emergence of shared modes. As such, it deals with their need to understand the relationship between shared modes and public transport, by studying mode choice in a multimodal network in which shared modes, metro, and other transport modes coexist. It does so by developing a mode choice model taking as an example the case of the city of Rotterdam. Considering the expected collaborations among transport operators already mentioned, it assumes a hypothetical scenario in which a perfect integration between SM and PT has been already achieved. Accordingly, it focuses on analysing the potential effects of collaborations between PT and SM providers to facilitate the integrated use of modes. The study explicitly considers shared modes as first/last mile alternatives in public transport journeys, as well as how they can influence choices for the whole trip chain.

All things considered, this study is driven by the following research question:

From the perspective of public transport operators, how could integration with shared mobility affect mode choices within an urban environment, and how to positively influence this?

To give structure to the methodology, and considering the research and design cycle presented in Figure 2, in order to answer the main research question it is important to first understand how do/could the presence of shared modes affect mode choice within an urban environment. Accordingly, the following sub-questions are also formulated:

- S1: Under which conditions/situations do shared modes and public transport compete or complement each other?
- S2: To what extent do sociodemographic characteristics affect mode choice towards shared modes?
- S3: Which is the perception of travellers (like or dislike) towards shared modes compared to other alternatives, and to what extent does it affect mode choices?
- S4: How do different attributes (*e.g. time, price*) of transport alternatives affect mode choices including shared modes?

1.5 Relevance

Scientific relevance

To the best of the author's knowledge, the literature about SM and PT integration is limited to current use of SM, perceptions of users and mode choice only for first/last mile travel. By studying mode choice including the effects of the presence of SM as a potential PT enabler, this study can represent a valuable addition to the scientific community.

Different factors have an important influence on the 'public transport - shared modes' interaction, some of them being closely related to the characteristics proper of the area of study. For instance, the layout of a city, living styles, people's preferences, among others play relevant roles in the adoption of SM, and for its integration with PT (Yan et al., 2020). Accordingly, it can be argued that this study might be appropriate to elucidate how the mentioned factors (and probably others) can affect the integration of SM and PT within the context of cities with similar characteristics to the one taken as an example in this project.

Relevance for transport providers

Currently, much effort is being done to improve the integration between SM and PT. Take for example initiatives of Mobility as a Service (MaaS) platforms in numerous cities. Accordingly, it is expected that in the near future both SM and PT services can be booked and paid using seamless systems. Furthermore, collaborations are in place to facilitate the availability of SM in public transport stations/areas. Nonetheless, the effects of that integration are uncertain, as well as how to potentiate the benefits to come with it. By means of this research, it is expected that transport providers can better anticipate the effects to come as a result of their collaboration. Furthermore, understanding how mode choice works is expected to provide valuable insights for the design and evaluation of policies, schemes, collaborations, etc., aiming to achieve more sustainable mobility.

1.6 Scope

First of all, it must be taken into account that the results are subjected to the characteristics of the area of Rotterdam and its surroundings, as the respondents of the SC experiment are based there, and the dynamics of the city and current patterns are expected to play a role in the choices they make. However, they are expected to be still applicable to a certain extent to other Dutch cities given the prevailing cycling culture around the country, the quality of public transport, and other characteristics they have in common. On the other hand, due to monetary and temporal constraints, this research is limited in terms of shared modes to *bicycles* and *mopeds*. This is also decided given the complexity that would be imposed on the project if all shared modes were to be included. Moreover, the current use of shared modes within the city highlights the great importance of the chosen modes, being those the most frequently used (Meijering, 2020).

In addition, as it will be further elaborated in Chapter 5, according to the research questions, different considerations are made for the SC experiment, some of which limit the scope of this research. For instance, some factors that are variable in reality are assumed to be constant. In that regard, it is important to highlight the assumption of PT and SM being already perfectly integrated. As a consequence, some important aspects that are expected to affect the acceptance of said integration cannot be studied in this research. For instance, the effects of the number of shared vehicles available, or the importance of seamless booking and payment systems. This limitation is accepted in this study, considering the mentioned tendency of transport providers to collaborate to achieve a level of integration similar to the one assumed in this study.

1.7 Report Structure and thesis outline

Overall, the methodology of the project consists in the development of a mode choice model, based on the principle of discrete choice modelling. Even though the methodology could be replicated in different contexts, it is important to treat the results carefully, since these are expected to be affected by the characteristics proper of the case in hand. In Figure 3 it is presented a workflow showing the overall methodology of the project.

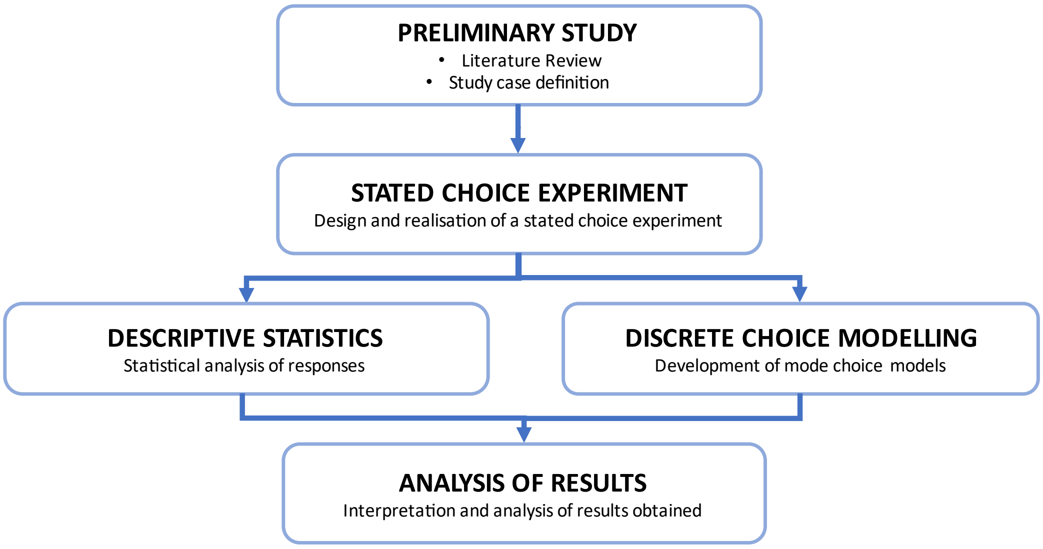

Figure 3. Workflow: Methodology of the project

Overall, the preliminary study aims to answer sub-question S1. In addition, it helps to collect relevant information for the design of the Stated Choice experiment. On the other hand, the analysis of the developed discrete choice models and the descriptive statistics gives the tools to answer sub-questions S2 to S4.

1.7.1 Main methods

As mentioned before, most of this research is related to choice modelling. Accordingly, it deals with preferences of people and the decisions they make and/or are expected to make in the future. The core of the project involves two interrelated methods: a *Stated choice experiment* and *Discrete choice modelling*.

Stated choice experiment

Depending on the way of collecting information, and the type of behaviour that wants to be studied, two main types of data sources can be distinguished within discrete choice models: *Revealed preference* and *Stated preference.* While the first one represents decisions people have made in real life, the second is based on hypothetical choice situations created by a researcher (Walker et al., 2018). Since this study deals with a hypothetical scenario in which shared modes and PT are fully integrated, *Stated preference* seems more adequate. Moreover, the use of *Revealed preference* data is not feasible, given the lack of a real-life scenario that matches the purpose and scope of the project.

To obtain the data, a *Stated choice experiment* needs to be designed and carried out. Designing a specific experiment for the project allows the author to create the experiment in such a way, that it fits as much as possible the scope and goal of the research. Furthermore, it is also useful in terms of achieving compatibility and consistency between the experiment and the other phases of the methodology (*i.e. discrete choice modelling and transport* model).

Discrete choice modelling

Discrete choice modelling is a method used to analyse and predict choices made by a decision-maker, considering a set of alternatives defined by different attributes (Ben-Akiva & Bierlaire, 2000). For the case of this research, the use of discrete choice modelling is closely related to the stated choice experiment. On the one hand, the discrete choice model to be estimated determines the design of the SC experiment. On the other hand, the outcomes of the SC experiment define the discrete choice model, which could be used in transport models that can help to understand expected modal splits, amongst other things.

Discrete Choice models are used to investigate factors affecting travel behaviour and to support the solution of policy questions (Muñoz et al., 2016), which makes it seem appropriate for the goal of this project. It is important to mention that the results of the research are expected to be useful in understanding policies/decisions to be made by RET, with regards to its response to the emergence of shared modes.

1.7.2 Report Outline

The report is composed of 8 chapters, organized into three main parts. The first part includes an introduction to the project, including the context applicable to it. In addition, it also presents the approach taken for the research. The second part includes the application of the methods and the analysis of the results obtained. The third and final part presents the conclusion and discussion derived from the results. The outline is presented in Figure 4.

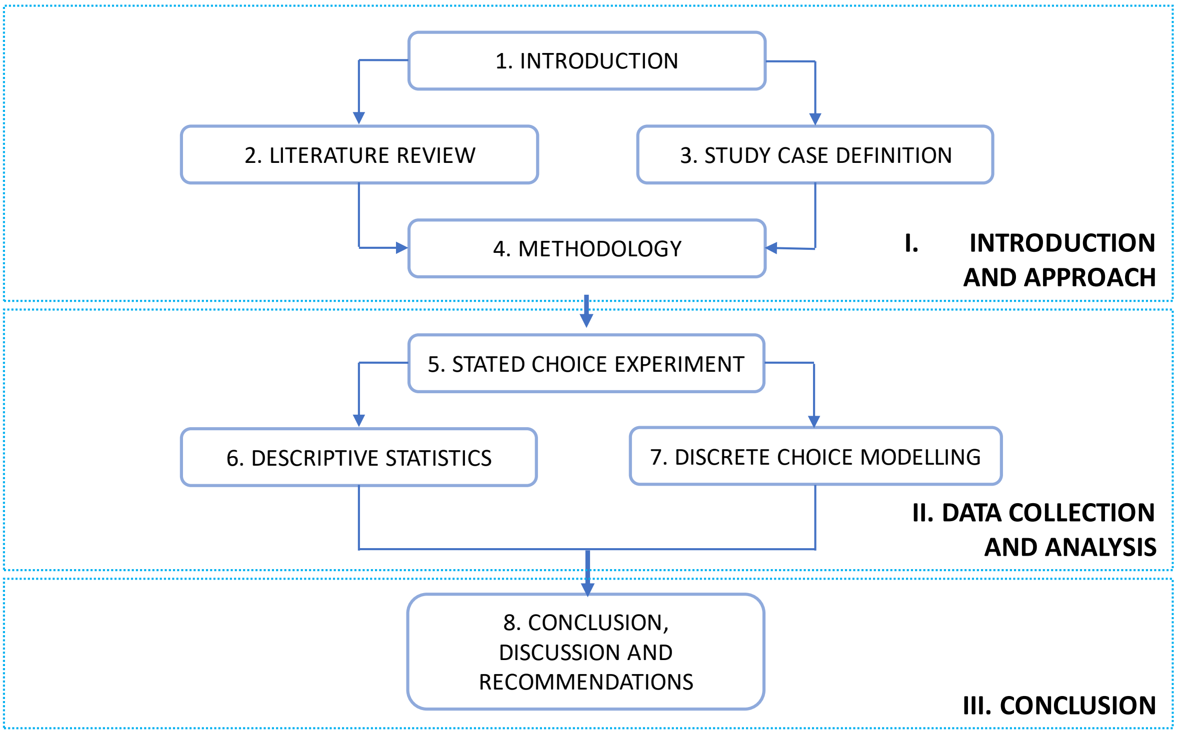

Figure 4. Report Structure

2 Literature Review

This chapter presents a literature review in which two main topics are studied. Firstly, mode choice with a special focus on the determinant factors that define it. Secondly, the relationship between shared modes and public transport. As mentioned in section 1.7 this part of the research has the objectives of collecting the information required to design the stated choice experiment, as well as giving a preliminary answer to sub-question S1.

2.1 Mode Choice

The choice of mode is one of the stages of a transport model. It refers to the distribution of travelling passengers among the different mode alternatives they have. It probably represents the most important element in transport planning and policy-making (Ortuzar & Willumsen, 2011). Taking as reference the 4-stage modelling approach, mode choice is the basis for the third stage, known as *Modal Split*. In this stage, travellers are distributed amongst the different modes available. Several studies can be found in literature in which mode choice is either the core of the study or at least is treated at some level. The most relevant principles and considerations of mode choice for this research are discussed in this section.

2.1.1 Attributes that affect mode choice

Mode choice is affected by numerous attributes that influence the preferences and thus the choices from users. Different authors have identified different factors, and have grouped them in various ways. For instance, Ortuzar & Willumsen (2011) suggest three types of factors influencing mode choice: *Characteristics of the trip maker, Characteristics of the journey and Characteristics of the transport facility*. The most relevant factors from this classification are presented in Table 1.

Table 1. Factors affecting mode choice (Ortuzar & Willumsen, 2011)

Factor	Classification
Car availability Possession of driving license Household structure	Characteristics of the trip maker
Trip purpose Time of day Travelling alone or with others	Characteristics of the journey
Travel time (an its components) Travel costs (an its components) Parking cost and availability Reliability of travel time Comfort and convenience Safety and security	Characteristics of the transport facility

Gandhi & Tiwari (2021) argue that sociopsychological variables also play a relevant role in mode choice. Through a study performed in Delhi, India, 13 factors were found to be relevant to explain mode choice behaviour. Those 13 factors include the mentioned sociopsychological variables, but also sociodemographic and instrumental variables, some of which overlap with the ones identified in Ortuzar & Willumsen (2011). The factors identified as well as the classification given to them are depicted in Table 2. Note that some of them coincide with the ones discussed in Table 1.

Table 2. Factors affecting mode choice (Gandhi & Tiwari, 2021)

Factor	Classification
Time Cost Comfort Safety	Qualitative instrumental variables
Habit Intention Perceived behaviour control Positive symbolism Negative symbolism Awareness norm	Sociopsychological variables
Education Household income Household vehicle ownership	Sociodemographic variables

In a different study, De Witte et al. (2013) reviewed existing literature with regards to modal choice and developed a framework to identify and structure the definition of modal choice determinants. The framework is displayed in Figure 5, and it presents the modal choice as a result of the interactions among four types of indicators. These determinants are located in two different levels in such a way that one includes three types of indicators: *socio-demographic, spatial, and journey characteristics* (outside circle); and the other one (internal circle)is only composed of *socio-psychological indicators*.

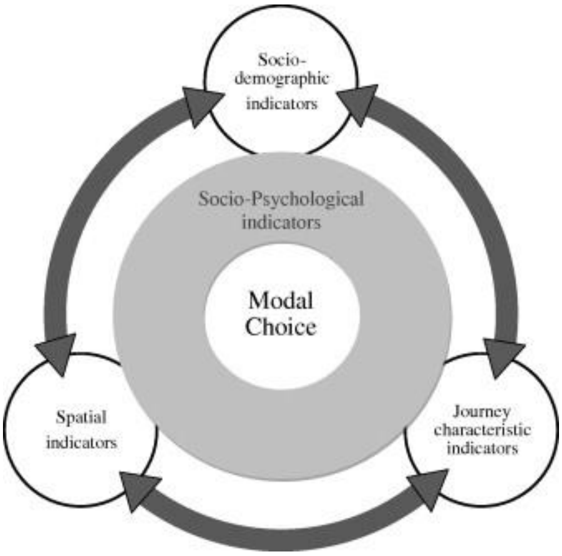

Figure 5. Framework for structuring modal choice determinants (De Witte et al., 2013)

2.1.2 Attributes relevant for access/egress mode choice

Despite being also a mode choice, and thus expected to be affected by the same factors discussed in 2.1.1, the choice of mode for access/egress leg can also be determined by other factors. To study this, Stam (2019) performed a literature review of different mode choice studies on multimodal networks. As a result, a framework for the access/egress mode choice was developed, in which five different types of factors were identified (see Figure 6).

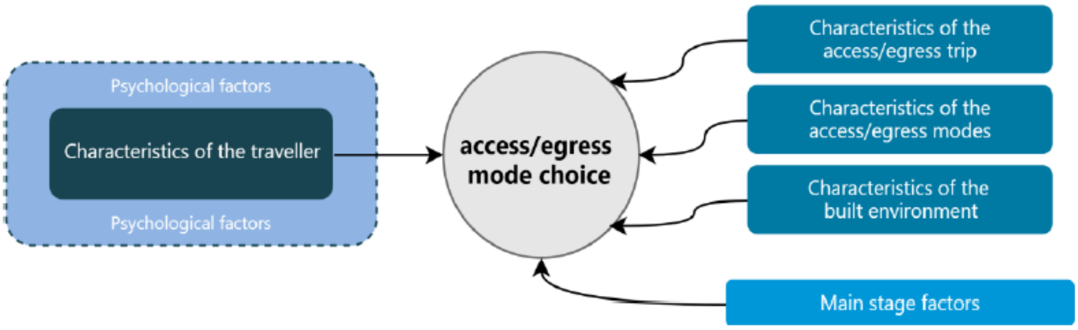

Figure 6. Access/egress mode choice framework (Stam, 2019)

After conducting a stated choice experiment to study egress mode choice from train stations, Molin & Timmermans (2010) found that context plays an important role in the choice of mode for egress legs of multimodal trips. The study highlights the effects of "trip purpose, distance, travel companions, amount of luggage, weather, route knowledge and time of day". According to the results, the choice probabilities of bicycle and walking as egress modes increase when the traveller knows the route, does not carry any heavy luggage, and the weather is favourable (*e.g. dry*). In the opposite cases, motorized vehicles such as public transport or taxi are preferred. With regards to socio-demographics, it highlights the effects of gender on preferences.

2.1.3 Mode choice: bicycle alternatives

Given the increasing interest in sustainable behaviour and active transport, the bicycle has become a very relevant transport alternative not only in The Netherlands but in many other places in the world. Bicycles are used both as the main mode and as access/egress solutions for multimodal transit trips and can be found in the form of private or shared vehicles. Multiple studies have been done in recent years to better understand the drivers behind choices for this mode. For instance, Muñoz et al. (2016) studied the role of latent variables in bicycle mode choice. It identifies some relevant variables determinant for bicycle mode choice, which include amongst others:

- Positive cycling experience
- Willingness to accept limitations of car travel
- Environmental concern
- Perception of "bikeability" in the city

- Physical activity propensity

Focused on multimodal transport, Brand et al. (2017) found that the use of the bicycle as shared mode is positively affected by high frequency and speed of public transport services. It highlights the potential of bicycle as access mode to public transport and the opportunity that might represent providing shared bicycles as egress options. These insights agree with the findings of Zhang & Zhang (2018), which suggest that increases in transit frequency are associated with increments in bicycle sharing usage. These effects are more clearly noticeable in high-density areas. Besides, Van Mil et al. (2020) found that people are in general willing to cycle longer when it helps to avoid transfers, which might be a very relevant aspect to consider in the planning of multimodal networks including transit and bicycle modes.

When analysing specifically the case of shared bicycles, other factors might be relevant to consider. In a study performed in Zurich, Reck et al. (2021) found that the most dominant factors in shared bicycle modal choice seem to be distance, time of day and vehicle density. The authors also found significant differences between preferences towards docked and dockless shared modes. Docked modes are preferred over dockless when trips are for commuting. Contrastingly, research done in Beijing suggests that effort and comfort are the most relevant factors influencing the choice for shared bicycles (Campbell et al., 2016).

2.2 Shared modes and Public transport

Some academics argue that shared modes can both complement and compete with public transport, according to numerous aspects. For instance, regarding bike-sharing, Ricci (2015) suggests that it can, at the same time complement and substitute public transport, depending amongst other things on the characteristics of the sharing scheme, the perception of users, the location of the stations, the public transport characteristics and coverage, etc. In a similar line, a study performed by Leth et al. (2017) in some North American cities, suggests that the relationship, and with it, the extent to which the modes compete and complement each other vary not only amongst cities but also between different areas of a single one. Moreover, car-sharing systems also seem to be both competition and complement to public transport, mainly depending on rental scheme attributes (one-way or two-way scheme) (Shaheen, 2016). This section presents an overview of when SM complement or compete with PT according to previous studies. Moreover, it includes a brief description of which factors affect the relationship between SM and PT.

2.2.1 Shared modes as complement to public transport

According to Oeschger et al. (2020), the integration of shared micro-mobility with public transport treated as a distinct mode could be seen as a sustainable transport mode. Especially considering that it takes the best of both modes, hence combining their strengths and advantages. While shared micro-mobility can offer flexibility and efficient accessibility, public transport offers higher speeds and larger spatial coverage.

Some data-driven studies have analysed the spatial distribution of shared modes trips with respect to public transport networks. For example, in a study performed in Oslo, Böcker et al. (2020) found that bike-sharing trips are frequently performed perpendicular to rail/metro routes, instead of parallel. In some North American cities, Leth et al. (2017) noticed that shared modes are used for tangential trips in peripheral areas of the public transport network, in which connections are not well developed. Both results suggest the potential of shared modes to fill gaps left by public transport. Such potential is mainly attributed to two inter-related arguments in favour of the notion of shared modes being complementary to public transport.

Firstly, shared modes have the potential to serve as access and egress modes. For instance, according to Böcker et al. (2020), bike-sharing could synergise well with public transport, by helping in access and egress legs. Furthermore, Oeschger et al. (2020) argue that the main potential of shared micro-mobility schemes relies on solving first- and last-mile problems, thus improving access to public transport. For first- and last- mile, shared modes can fill the gap left by the lack of availability of private modes (van Kuijk et al., 2021).

The improvement of first- and last- mile, as suggested in the literature is highly correlated with consequential increases in coverage and accessibility of public transport (Ji et al., 2018; Leth et al., 2017; McLeod et al., 2017; Oeschger et al., 2020; Shaheen, 2016). In that regard, Leth et al. (2017) suggest that the support provided by bike-sharing services in low-density areas of a city might help to improve coverage of public transport. It is important to mention that as argued by Meng et al. (2020), in those areas public transport networks are usually not well connected, hence are unable to serve all locations. Shaheen (2016) and Ji et al. (2018) also highlight the potential of shared mobility for addressing first- and last-mile connectivity with public transit. Shared modes, they say, have the potential of extending catchment areas of public transport, encouraging multimodality, and thus becoming more attractive for users. The latter might potentially cause modal shifts away from private car (Oeschger et al., 2020). Supporting those arguments, in a study performed in Oslo, Böcker et al. (2020) found that the highest use of bike sharing is in those areas where rail/metro networks are not properly connected.

In addition to the improvement of access/egress and the expansion of coverage, some other potential benefits of a good synergy between public transit and shared modes, are discussed in the literature. For instance, Ricci (2015) highlights that shared modes could help to manage public transport demand, by for example reducing overcrowding or helping to integrate different modes. The latter agrees with findings by Böcker et al. (2020) that show high bike sharing usage to connect rail and metro networks, as well as to transfer between stops. Besides, McLeod et al. (2017) discuss that shared modes can also serve sporadic travel needs that can't be properly served with traditional public transport modes, for example, leisure trips. Ji et al. (2018) on the other hand, state that sharing systems can help to reinforce the ridership of public transport by improving its efficiency.

2.2.2 Competition between Shared modes and Public transport

Nevertheless, as mentioned before, shared modes are said to be not only a complement but also a competition to public transport. Leth et al. (2017) for example highlights that according to their study, in high-density areas bike-sharing represents a direct and faster option against the use of public transport. Something similar holds for congested parts of public transport networks, like city centres, where shared modes can offer lower travel times and costs compared to public transport (Machado et al., 2018). Long travel times by public transport are an important deterrent to the use of such modes, as such, they might encourage switches to shared modes as long as the latter are considerably faster (Leth et al., 2017). Likewise, car-sharing can cause a certain decrease in public transport ridership, especially when the rental scheme is 'one-way' (Shaheen, 2016).

2.2.3 Relevant factors for integration

In order to discuss what affects the integration between public and shared modes, it is important to first understand what integration means in the transportation field. Ibrahim (2003) defines it as moving from one place to another using multimodal transport facilities and interconnection characterised by their user-friendliness. Enhancements in the integration of transport modes help users to travel more easily since inconveniences are reduced. The study identifies different types of integration: *fare, information, physical, network, planning and management.* Partially based on that, Brand (2015) elaborates further on the concept of Transport Network integration, which is then defined as:

> *"The combination of individual elements of the transport chain, form a traveller's origin to its destination, with the aim to positively influence the performance and effects of the transport system. This combination entails the integration of the different elements (modalities) through improvement of the performance of mode specific characteristics that influence integration, taking into account the entire system"*

Integration between transit and shared mobility has been discussed in different publications in recent years, from which some important factors affecting it can be mentioned. For instance, Oeschger et al. (2020) highlight that to promote and improve the integration between shared mobility and public transport, both systems should be planned together - as a whole- considering the synergy between them and the strengths and possibilities that each offer. Given the reliance of planning practices on government policy, better involvement and intervention is suggested to meet multi-modal shared mobility supply and demand. Furthermore, multi-modal shared mobility requires improved infrastructure to be successful. For instance, shared modes require parking facilities at accessible locations and at public transport stops (Meng et al., 2020), as well as high docking capacities near stations (Böcker et al., 2020; Oeschger et al., 2020). The latter is highlighted as an important factor to reduce uncertainty, thus encouraging the consideration of shared modes during trip planning.

Moreover, the main potentials highlighted in 2.2.1 should be considered. For instance, to encourage multimodality (integrating Public transport and shared modes), conditions to make shared modes available for access and egress should be met. As stated by Böcker et al. (2020), shared-mobility use frequencies are positively affected by the proximity of route ends to public transport stops. Likewise, Yan et al. (2020) highlight the importance of land use and population density around public transport stations for the adoption of bike-sharing.

Pricing schemes and payment mechanisms are also considered relevant. It is argued that uniform ticketing systems, as well as integrated mobile phone apps, might improve integration as they allow the integration of real-time data, hence making transfers more efficient and improving user-friendliness (Böcker et al., 2020; Ma et al., 2020; Oeschger et al., 2020; Shaheen, 2016).

2.2.4 Experience in The Netherlands

In Utrecht, van Kuijk et al. (2021) performed a stated choice experiment to study user preferences for shared modes as last-mile connections with public transport. The results of the study suggest that most public transport users prefer not to use shared modes as part of their trips. The ones who use it, nonetheless, prefer shared bikes (both traditional and electric) over e-scooters and e-mopeds. The authors suggest considering the provision of shared modes in major public transport stations and hubs. The latter, they argue might improve the overall experience of an important number of travellers. Similarly, Arendsen (2019) performed a stated choice experiment studying the use of shared modes as access or egress modes. In this case, the focus was on multimodal trips including trains. The results, agree with the ones by van Kuijk et al. (2021), as shared bikes showed to be the preferred mode among different shared-mobility alternatives. Some important factors for the adoption of shared modes highlighted for the study include distance, costs, parking facilities, etc.

In Delft, a case study was performed by Ma et al. (2020) to study how bike-sharing systems affect modal split. The findings suggest that the use of shared bicycles cause reductions in walking, private bike, bus, tram and car use. Nonetheless, something different happens regarding train, for which usage increases. Price is highlighted in the study as an attribute with high influence in decisions about whether to use or not shared bicycles.

A case study in The Hague was performed by Geurts (2020), where a multimodal network design approach was developed, together with a framework for the assessment of such networks. The project, as he states might contribute to a faster implementation of multimodal networks based on the cycling-transit combination, by allowing operators where to locate bike docks and to evaluate different potential approaches to do so.

2.2.5 Conclusion

The relationship between public transport and shared modes is rather complex, and whether it is complementary or synergetic depends on various factors. Nonetheless, different studies have found that a good integration of modes might help to enhance public transport services. For instance, by solving first- and last-mile connections, shared modes have the potential to increase public transport coverage as well as to improve its accessibility. Moreover, by offering direct and fast alternatives, they could reduce overcrowding in public transport vehicles, especially in the most congested parts of the network and during peak hours. Nonetheless, supplementary relationships have also been found. The synergy is affected heavily by factors related to the existing PT Network and by the way SM and PT are integrated.

3 Study case definition

As described earlier, the project is developed under the circumstances of the transport network of Rotterdam and its neighbouring municipalities. More specifically within the case of its public transport and shared mobility services. In this section, the most relevant characteristics of such a context with regard to the scope of the project are highlighted. It is important to remember that even though the context is expected to affect the outcomes of the project, the results are not necessarily limited to it, as some of them could still apply to other municipalities or transport systems with similar characteristics.

3.1 Rotterdam

Rotterdam is the second-largest city in the Netherlands (*Netherlands*, 2016). This city, located in the province of *South Holland,* is part of the region known as ‘the Randstad’, the most heavily populated and developed region in the country (Moca-Grama, 2020). It is divided into 14 districts that are also subdivided into numerous neighbourhoods. The map of the city, with its division in districts, is displayed in Figure 7. As it can be noticed in the picture, the city is divided into south and north areas. Such a division is made by the *Nieuwe Maas river* (CityR, 2021). One of the main attractions of the city, is the *Port of Rotterdam,* one of the five biggest harbours in the world, and the biggest in Europe (*Netherlands*, 2016).

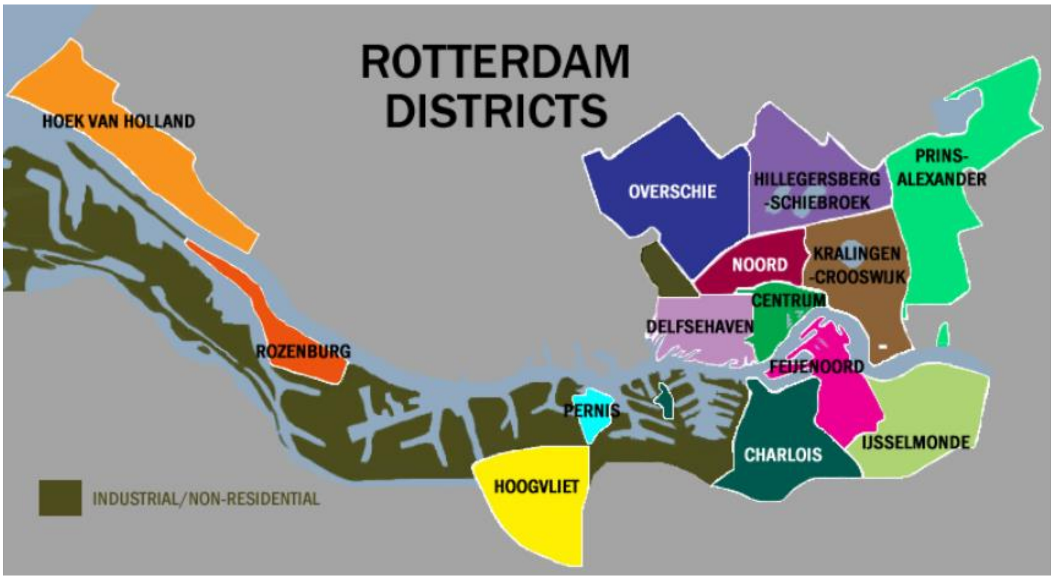

Figure 7. Rotterdam districts division. (c) ExpatINFO Holland 2021

It is important to highlight that Rotterdam is the second most populated city in the Netherlands. In Table 3 below, some key figures related to the population in Rotterdam are presented.

Table 3. Key Figures – Population Rotterdam Source: CBS (Centraal Bureau voor de Statistiek, 2021)

Characteristic	
Number of inhabitants	≈ 651.6 thousand
Men/Women proportion	97/100
Growth in 2020	474 people (0.07 per 1000 inhabitants)
Forecast population growth (2018-2035)	14.65 per 1000 inhabitants

Migration represents an important feature of the city. By January of 2018, just over half of the population in Rotterdam had a migration background, which together with Amsterdam was the highest in the country. The 'Centraal Bureau voor de Statistiek' (CBS), makes a distinction between western and non-western migration. In terms of the latter, Rotterdam is the leading city, with 38% of the population having a non-western background (*i.e. from Turkey, Marocco, Surinam, etc*). (Centraal Bureau voor de Statistiek, 2021)

Mobility

Rotterdam has several transport options for travellers. It is possible to travel by public transport, bicycle, car, on foot or using shared modes than can be found throughout the city. Public transport is provided by the RET, whose services include bus, tram, and metro (van den Broek, 2021). Interestingly, in the city centre (the densest area in the city) egress from PT is mostly performed on foot (Gemeente Rotterdam, 2020). In addition to the traditional PT modes, there is also the possibility of travelling by taxi. In that case, it is possible to choose a car taxi, bike taxi or water taxi.

In terms of private vehicles, both cars and bicycles are widely used in the city. The share of car trips by 2019 was 42% of total trips made in the city. However, in the city centre, those numbers are declining, while the use of Public transport and bicycles is increasing (Gemeente Rotterdam, 2020).

Finally, a new type of transport means has emerged in the last years: *Shared modes.* Currently, different shared modes can be in the city, including bicycles, mopeds (also known as scooters) and cars. It is important to mention, that different to most other European countries, in the Netherlands the e-scooters, or *'steps'* -how they are popularly called in the Netherlands- are not allowed (Kraniotis, 2020). Rotterdam is not an exception to that regulation. Thus, this type of vehicles is not found in the city.

Rotterdam Mobility Approach

The Mobility approach adopted for the city in 2020, has the objective of improving accessibility within the city. In order to achieve that, it intends to reduce trips in the city by car and to reduce congestion within the city centre. The approach aims for people to choose more often public transport and active modes (*walk, bicycle*). Accordingly, it places the pedestrian as the core of mobility-related policies, guaranteeing more space in neighbourhoods, the city centre and major public transport stations.

In terms of Public transport, it is pretended that Public transport ridership grows in the south of the city, and to make PT better accessible in the city. In the city centre, it is intended that the share of Public transport trips (including walking) increases to 29% by 2030, and 34% by 2040 (Gemeente Rotterdam, 2020).

3.2 Public transport operator - RET

RET is the public transport company of the metropolitan region of Rotterdam. It is in charge of both vehicles and infrastructure related to its transport services, including management and maintenance. The company offer includes services of bus, tram, metro and fast ferry. The combined daily ridership is about 650.000 people. The number of lines, vehicles, and stops for Bus, Tram, and Metro are displayed in Table 4, while the maps of the tram and metro networks are displayed in Figure 8.

Table 4. Overview of vehicles and lines - RET (*RET*, 2021)

	Lines	Vehicles	Stations/Stops
Bus	58	293	
Tram	9	112	322
Metro	5	167	62

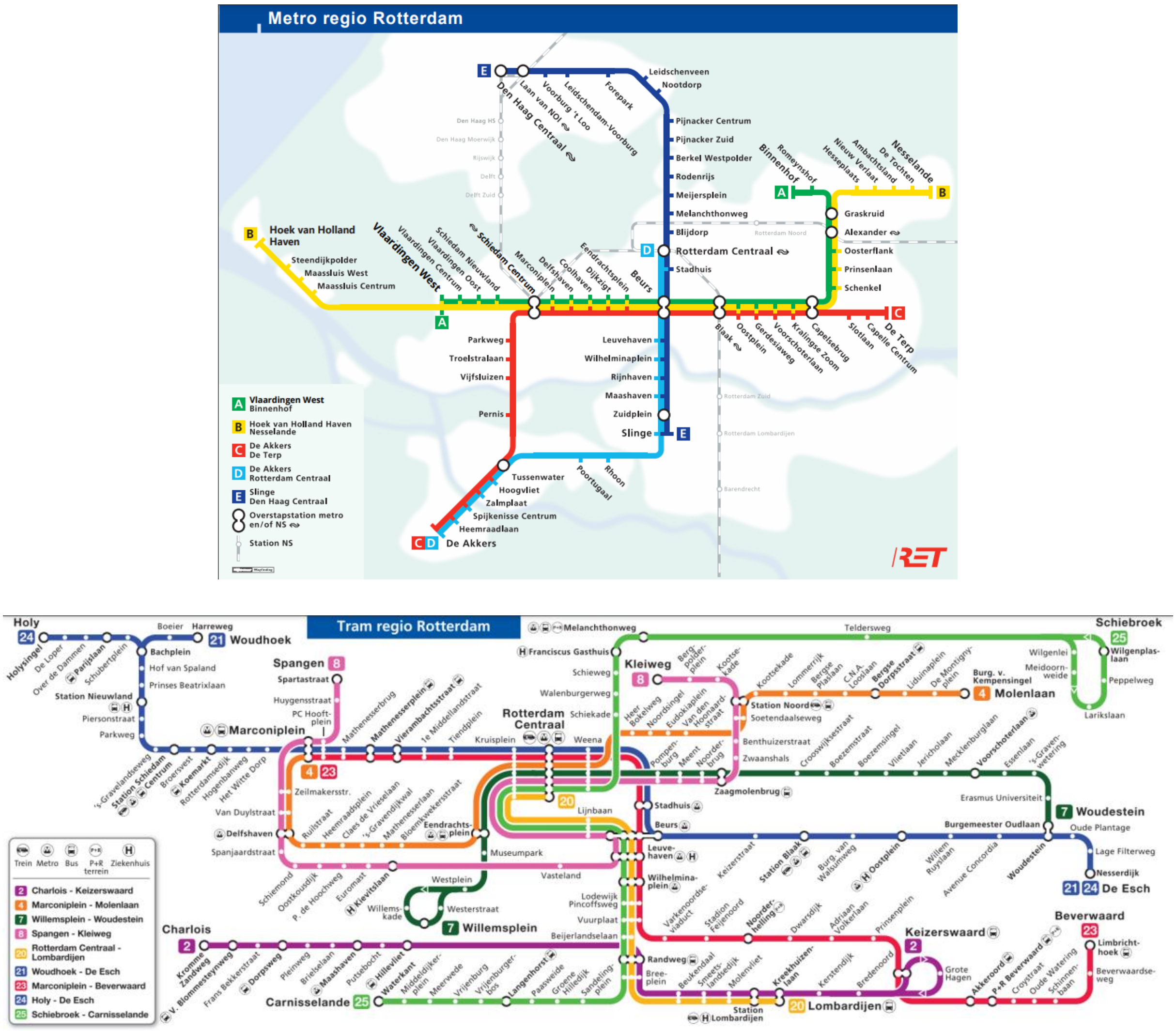

Figure 8. RET Network maps. Top: Metro, Bottom: Tram (*RET*, 2021)

It is important to highlight that as part of its mission, RET is interested in the improvement of the whole transport system in Rotterdam. In concordance with that, they are currently working together with other stakeholders to improve the transport offer to travellers within the city. For instance, they collaborate with shared mobility providers to try to achieve better door-to-door transport (*RET*, 2021).

3.3 Shared modes use and perception

Given the interest in understanding the mobility dynamics within the Rotterdam area, different studies have been already performed to study the preferences regarding shared modes. The results of such studies are considered in this research since they can provide valuable information for the decisions to be made in the next stages of the project.

First, in a survey carried out by the Municipality of Rotterdam in 2020, some travellers were asked different questions regarding their use of two-wheelers (*i.e. shared bicycles and shared mopeds*). According to the results obtained, it is noticed that the use of shared mopeds seems considerably more common than that of shared bicycles (see Figure 9). Note that at the moment of the survey OV-fiets was the preferred shared bicycle operator. The latter is interesting considering the difference in the rental scheme between OV-fiets and the other shared bicycle operators in the city; while most shared bicycle services in the city are dock-less, OV-fiets scheme follows a station based approach. Furthermore, it has a fixed price in which the duration of the rental period does not have any influence, which makes it especially convenient for long rental periods (several hours within a single day).

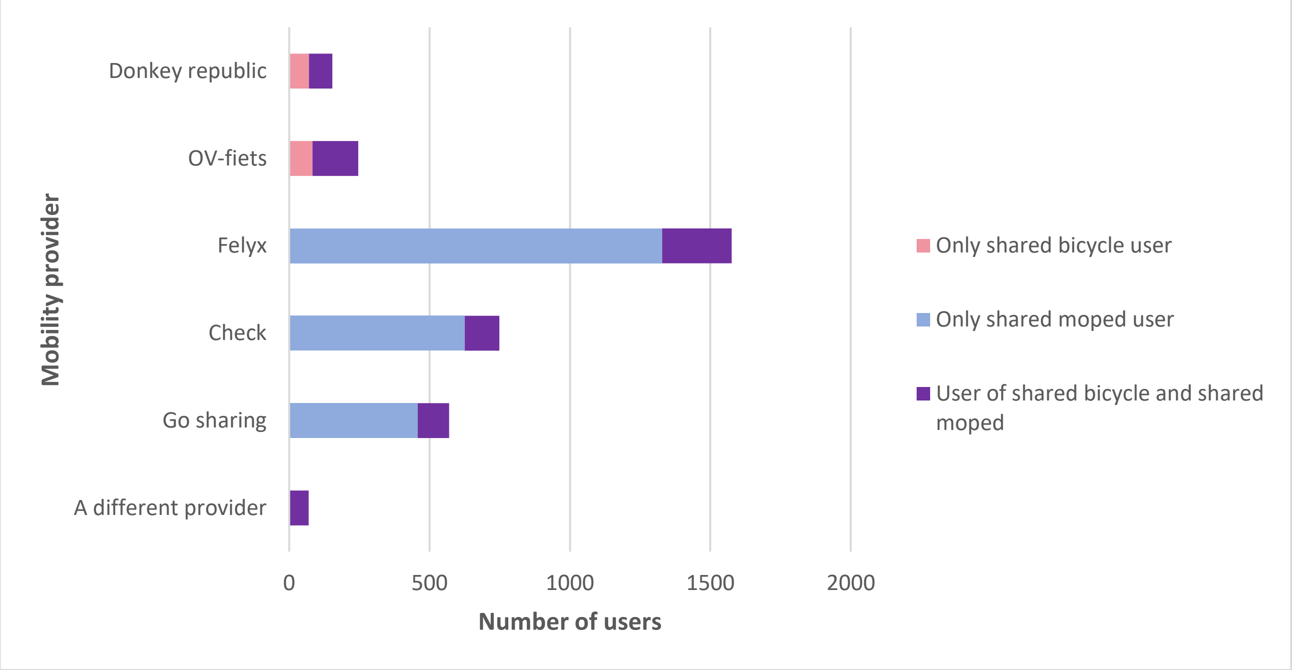

Figure 9. Use of two-wheelers – Adapted from (Meijering, 2020)

In addition, respondents of the survey were also asked to indicate how often they use shared modes, for which the results are presented in Figure 10. Note that despite being mostly used occasionally (less than once per week), a considerable proportion of respondents use shared mopeds and shared bicycles regularly (at least once a week). Concerning the former, the proportion of regular users adds up to nearly 40%, while for shared bicycles it is slightly below 20%. Despite the big difference in use between both modes, both seem to have a place in the market that should not be ignored.

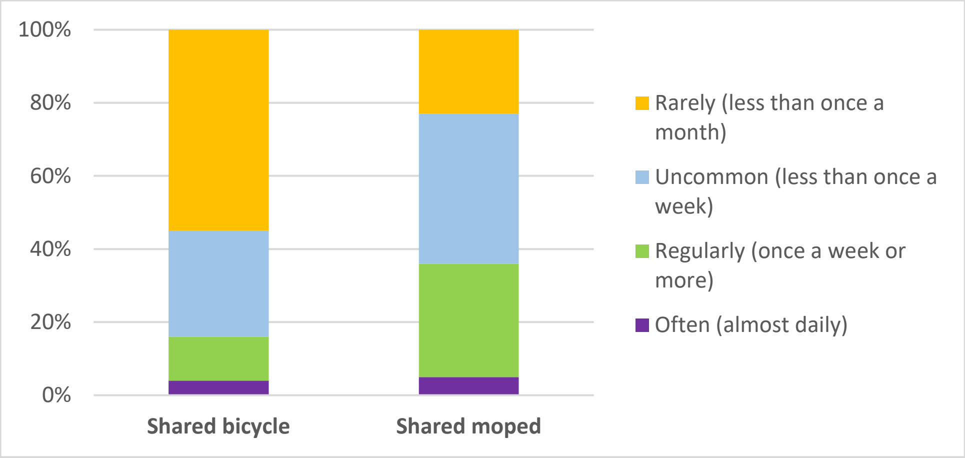

Figure 10. Frequency of use of two-wheelers – Adapted from (Meijering, 2020)

The purpose of use of two-wheelers within Rotterdam includes many different motives. The most common are leisure, recreation and meeting friends and family. Nonetheless, around 20% of users (for both shared bicycles and shared mopeds) use them for commuting and education purposes. In Figure 11 the distribution of motives per mode is displayed.

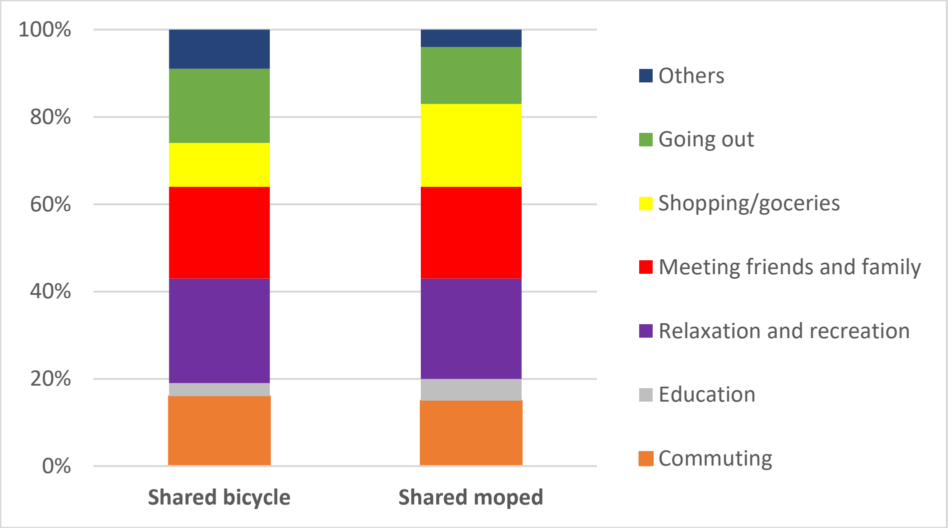

Figure 11. Purpose of use of two-wheelers – Adapted from (Meijering, 2020)

Finally, for the purpose of this study it is important to understand the relationship that two-wheelers might have with other modes of transport. Accordingly, they were asked to indicate with which modes of transport they combine shared modes in multimodal trips; the results are displayed in Figure 12.

Note that from both shared modes, shared bicycles are the ones more often used for multimodal trips involving other transport alternatives. On the other hand, train and metro are the PT modes with which two-wheelers are more often combined, hence suggesting a potential complementary relationship. Contrastingly, since they are not very commonly combined with buses, it could be argued that a predominantly competitive relationship is expected.

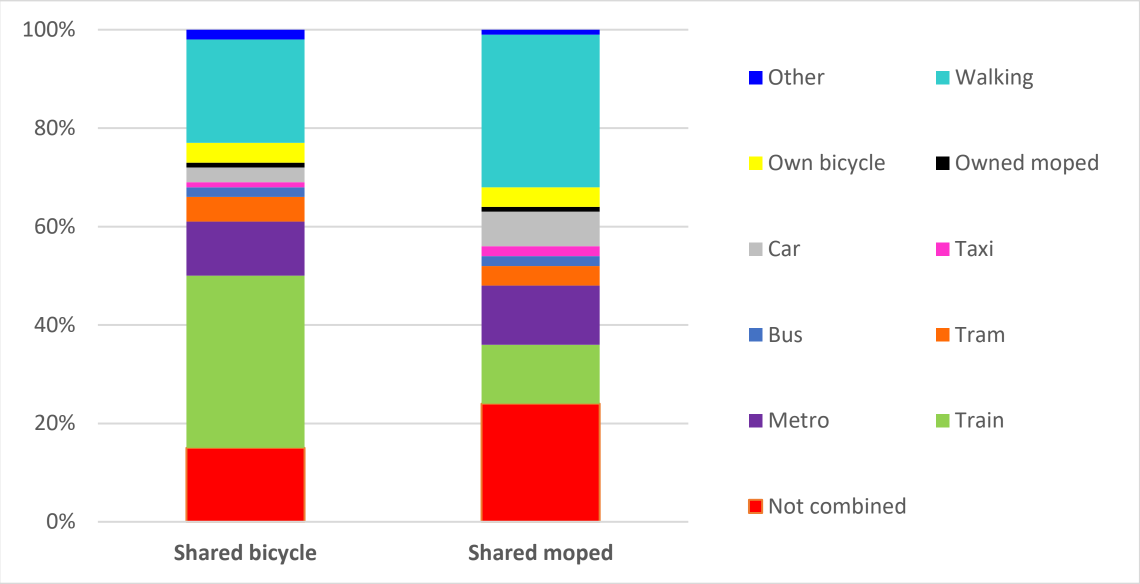

Figure 12. Combination of shared modes with other modes in multimodal trips – Adapted from (Meijering, 2020)

In addition to the survey, given the need to understand the use of shared mopeds and shared bicycles, RET has recently analysed the use of shared mopeds and shared bicycles in the most important hotspots in Rotterdam (*RET,* 2020). Three shared mopeds operators were included: *Felyx, Check* and *GoSharing*. For shared bicycles, on the other hand, only *Donkey Republic* was included. The study includes the records for the rental of vehicles that either started or finished at one of the hotspots, for several days in 2020. In addition to the identification of the most relevant hotspots in terms of shared mobility, the study highlighted that the use of two-wheelers is higher during weekdays than on weekends.

To sum up, from the information presented in this subsection some important insights are taken, which are used in the methodology adopted in the research. Firstly, the fact that some travellers consider shared vehicles for their journeys on a rather regular basis supports the idea of this research being potentially relevant according to the current mobility dynamics in cities. Secondly, even though the use of shared bicycles and shared mopeds do not give the impression of being limited to specific trip purposes, it seems that for some motives people consider them more than for others. Hence, it might be relevant to study the effects of different trip purposes on the likelihood of people using shared modes. Thirdly, the results suggest that two-wheelers are more likely to be combined with train and metro, rather than with tram and bus. Accordingly, it might be interesting to study complementary relationships of SM with metro, while competition could be evaluated especially with bus and tram. Finally, it is important to consider that both shared bicycles and shared mopeds are used not only in combination with other transport modes but also as individual alternatives.

4 Methodology

4.1 Stated Choice experiment

The stated choice (SC) experiment has the purpose of obtaining the data required for a discrete choice model, while also determining the influence of different attributes on people' preferences. In these type of experiment, respondents are asked to choose an alternative from a set of hypothetical options constructed by the researcher. Each option is defined by a set of attributes, which vary during the experiment (Ortuzar & Willumsen, 2011). This kind of experiment is widely used in different fields, including the transportation sector. They allow the estimation of the influence of different design attributes in the choices made by individuals participating in the experiment.

To create SC experiments, it is necessary to define the problem in hand, the alternatives to be included, the attributes that characterise those alternatives, the values that can take those attributes, amongst other things (Walker et al., 2018). Those things to be defined can be divided into three main phases: *Model specification, experimental design* and *Questionnaire* (Choicemetrics, 2018).

4.1.1 Model specification

SC experiments are created for estimating specific models. Accordingly, it is necessary to first define some characteristics of the model to be estimated: the alternatives to be included as well as their respective attributes. Said characteristics need to be defined in the shape of utility functions, which need thus to include the parameters that need to be estimated. In this part of the process, it needs to be defined whether attributes are generic to all alternatives or alternative specific. (Choicemetrics, 2018)

4.1.2 Experimental design

According to the model specification, the experiment needs to be designed. The process has the objective of defining which specific choice tasks respondents will face. The result of this phase can be described as a matrix summarising the way levels are varied among the different choice tasks. It includes multiple decisions, some of which are presented in this sub-section (Choicemetrics, 2018).

Will alternatives be labelled or unlabelled?

Unlabelled alternatives are those in which the names of the alternatives do not represent a characteristic (*e.g. option 1, option 2, option 3,* etc). Contrastingly, in labelled alternatives, the name of the alternatives represent characteristics not varied in the experiment (*e.g. car, train, bus, etc*) (Molin, 2019). In case the model specification includes alternative-specific parameters, the experiment must be *labelled*. On the other hand, if the alternatives have generic attributes (*i.e. applicable to all alternatives*) the experiment can be *unlabelled* (Choicemetrics, 2018).

Attribute levels

The number of levels to be included in the experiment depends on the model specification previously defined. Typically the number of levels per attribute is limited to between 2 and 4 (Molin, 2019). If non-linear effects are expected for an attribute, at least 3 levels are required to estimate the mentioned effects. However, it is important to keep in mind that the higher the number of levels, the higher the number of choice tasks needed (Choicemetrics, 2018).

On the other hand, regarding the range of levels, it should be wide enough to include current and possible future values, while still being reasonably believable to respondents. Nonetheless, it is important not to use ranges too wide, since this might cause choice tasks to have dominated alternatives (Choicemetrics, 2018).

Type of design

There are different types of experimental designs. Which one to choose depends on different factors, like for example the number of attributes and levels to be included or the desired number of choice situations. The most common types of design are *full factorial, fractional factorial* and *efficient* designs. The latter refers to designs that aim to obtain designs that generate parameter estimates with the smallest standard errors possible (Choicemetrics, 2018). In order to be able to generate these types of designs, it is necessary to have some information about the expected parameters to be estimated. Said information is used to define *prior* values for the parameters. The quality of the design highly depends on the quality of the priors. The closer they are to the true parameter in the population, the more efficient the design is (Walker et al., 2018).

4.1.3 Questionnaire

The final stage consists of creating a questionnaire according to the experimental design. The questionnaire must be constructed in such a way that respondents understand what is asked of them, as well as the context under which they are asked to make the choices. Questionnaires can be either performed using online tools or manually using pen and paper. (Choicemetrics, 2018)

4.2 Discrete choice modelling: Mode Choice

Mode choice, similar to other travel behaviour aspects, is usually studied in a disaggregated way, in which decisions are made by individuals. The usual methodology used to do so is Discrete choice analysis, in which decision-makers have to choose between a given set of alternatives. The general framework of Discrete choice modelling is defined by the following characteristics: *a decision-maker, a set of alternatives, a set of attributes defining those alternatives, and a decision rule* (Ben-Akiva & Bierlaire, 2000). Applied to this research, such characteristics are defined as follows:

- *Decision maker:* Travellers, who need to make a choice regarding which mode(s) to use for a given trip
- *Alternatives:* The different modes available for the travellers, for such a trip (*e.g. car, bicycle, shared moped, etc.*)
- *Attributes:* Characteristics defining each alternative for the given trip (*e.g. travel time, travel cost, level of comfort, etc*)
- *Decision Rule:* The reasoning behind a choice made by the decision-maker with respect to which alternative to use, given its respective attributes.

The first three characteristics are based on the Scope discussed in Section 1.6 and the characteristics of the Case study described in Chapter 3. The decision rule, on the other hand, is somehow independent of the Case study. The remainder of this section (4.2) will discuss the main considerations about the decision rule, assumed for this research.

4.2.1 Random Utility Maximisation (RUM)

Random Utility Maximisation is the most widely used decision rule used in transport-related discrete choice modelling. It is based on *Utility theory*, which in short assumes that the preferences of decision-makers are driven by the numeric evaluation of each alternative, from which the best evaluated is chosen. The evaluation of each alternative is defined by its attributes, which added return a value, called '*utility'.* However, the decision-maker does not have perfect discrimination capability. Thus it is assumed to have incomplete information, and consequently uncertainty also plays a role (Ben-Akiva & Bierlaire, 2000). Accordingly, the utility of an alternative *i,* for a decision-maker *n* (U_{in}) is defined as

$$U_{in} = V_i + \varepsilon_{in} \tag{1}$$

Where V_i is the systematic utility and ε_{in} the error term. The systematic part of the utility is related to its observed attributes, whereas the error term includes everything else influencing individual's choice, like for instance unobserved factors, heterogeneity amongst individuals, *etc.*(Van Oort, 2019). The systematic utility, is defined as

$$V_i = \sum_m \beta_m \times x_{im} \tag{2}$$

In the equation: β_m represents the relative importance of attribute *m,* and x_{im} the numerical value of alternative *i* for the respective attribute *m*. According to the RUM model, an alternative *i* is chosen by a decision-maker *n* if its utility U_{in} is greater than that of all other alternatives *j*, as expressed by

$$U_{in} > U_{jn}, \forall j \neq i \tag{3}$$

4.2.2 Model specification

How the utility defines the probability of an alternative being chosen is defined by the type of discrete choice model applied. The different models are defined according to how they deal with the random part of the utility. There are two main families of models: *Probit* and *Logit* models. Probit models can capture all correlations among the different alternatives. Nonetheless, its application is limited due to the great complexity of its formulation. Logit models on the other hand are widely used for travel demand analysis, due to their tractability (Ben-Akiva & Bierlaire, 2000). In this sub-section, three logit-based models relevant for this study are briefly explained.

Multinomial Logit model (MNL)

The most widely used discrete choice model. This approach assumes that the random part of the utilities are independently and identically Gumbel distributed (IID) (Ben-Akiva & Bierlaire, 2000). As a result, the error terms of different alternatives are uncorrelated. According to the model formulation, the probability of an alternative i being chosen from a set of alternatives C can be expressed as (Ortuzar & Willumsen, 2011):

$$P_i = \frac{\exp(\beta\, V_i)}{\sum_{j \in C} \exp(\beta\, V_j)} \tag{4}$$

The relationship of the probabilities of any two alternatives does not depend on the choice set, but on their own utilities. Hence, they are unaffected by the systematic utilities of other alternatives (Ben-Akiva & Bierlaire, 2000). Consequently, it ignores correlations that might exist between the non-systematic part of the utility of some alternatives (Van Oort, 2019). In order to deal with that shortcoming, other approaches have emerged, which are presented ahead in this sub-section.

Nested logit model (NL)

The Nested logit model is derived from the MNL model, in which some of the correlations between alternatives are captured. It is based on the principle of partitioning the choice set C into nests (Ben-Akiva & Bierlaire, 2000) . Each nest is a group of alternatives that are correlated (or similar), and is represented by a "*composite alternative*" that competes with the other alternatives or nests if there are more (Ortuzar & Willumsen, 2011). In this case, the utility function of each alternative includes terms specific to the nest and others specific to the alternative itself. Assuming that and alternative *i* belongs to a nest *m,* the utility function for a decision maker n would like this:

$$U_{in} = V_i + \varepsilon_{in} + V_m + \varepsilon_{mn} \tag{5}$$

Both error terms in the equation are assumed to be independent. ε_{in} is an error term independent for each alternative and holds the IDD property. ε_{mn} on the other hand, is the error term associated to the nest, and is common between the alternatives part of it.

Mixed logit model (ML)

The ML model is also derived from the MNL approach. It can be seen as a generalisation of the MNL model, and it is recognised by its ability to capture three things that the standard MNL approach cannot: Nesting of alternatives, parameter heterogeneity and correlation between observations over time made by same individual (Van Oort, 2019). It does so by allowing the addition of random parameter variation, unrestricted substitution patterns and correlation in unobserved factors of observations during time (Train, 2002).

Mixed logit is based on its choice probabilities, which are the integral of logit probabilities $L_i(\beta)$(see equation 4) over a density of parameters $f(\beta)$(Train, 2002). It can be expressed as it follows:

$$P_i = \int L_i(\beta) f(\beta) d\beta \tag{6}$$

In order to capture nesting effects, the ML model formulation adds an extra error component to alternatives that share characteristics, hence relaxing the IID property. Similarly, to capture parameter heterogeneity it assumes that parameters are distributed across the population, thus adding an extra error component per each parameter, which represents their respective standard deviation. This is done since parameters are expected to vary across people, and not to be constant across the population as assumed by previous formulations (Van Oort, 2019). Given that ML can capture nesting of alternatives, taste heterogeneity and panel effects, it is adopted in this research instead of NL.

4.2.3 Goodness of fit

Different indicators exist that can be used to evaluate the performance of the estimated models. One of the most widely used indicators in discrete choice modelling is the McFadden's rho-square (Train, 2002), which is formulated as it follows:

$$\rho^2 = 1 - \frac{LL(\beta)}{LL(0)} \tag{7}$$

In the formula $LL(\beta)$ represents the log-likelihood of the estimated model, whereas $LL(0)$ represent the log-likelihood of the models if all the betas were zero. This indicator takes values between 0 and 1 and represents the percentage of the initial uncertainty explained by the model (Van Oort, 2019). In addition to McFadden's rho-square there are other model fit indicators used in choice modelling. For instance, the Akaike Information Criterion (AIC) or de Bayesian information Criterion (BIC). However, as they are not used in this study, they are not discussed further.

PART II:

Data Collection and analysis

5 Stated Choice experiment

According to the goal of the project described in Chapter 1, a Stated Choice (SC) experiment is designed. The different characteristics of the experiment, as well as the considerations for the design, are presented in this chapter. The multimodal network considered for this study includes a great variety of relationships and mode choice related decisions. The focus of the SC experiment, and with it the information expected from it, are defined according to the Scope and the objective of the research.

A 2-step approach is defined for the experiment. The approach includes two transport mode decisions related to one another, for each choice situation. Each situation assumes a trip from home to a leisure/commute destination within the city. For the first choice (step 1) it is assumed a multimodal trip -only main leg and egress- in which the first part of the trip is travelled by train. The respondents face a choice task in which they are asked to specify their preferred egress mode (see Figure 13). This choice task is intended to understand the willingness to use Shared modes as a last-mile enabler for metro trips. In addition, it also allows the analysis of perception towards shared modes in comparison with other egress modes (*e.g. walking*). For the remainder of the report, this choice task is called e*gress mode choice*.

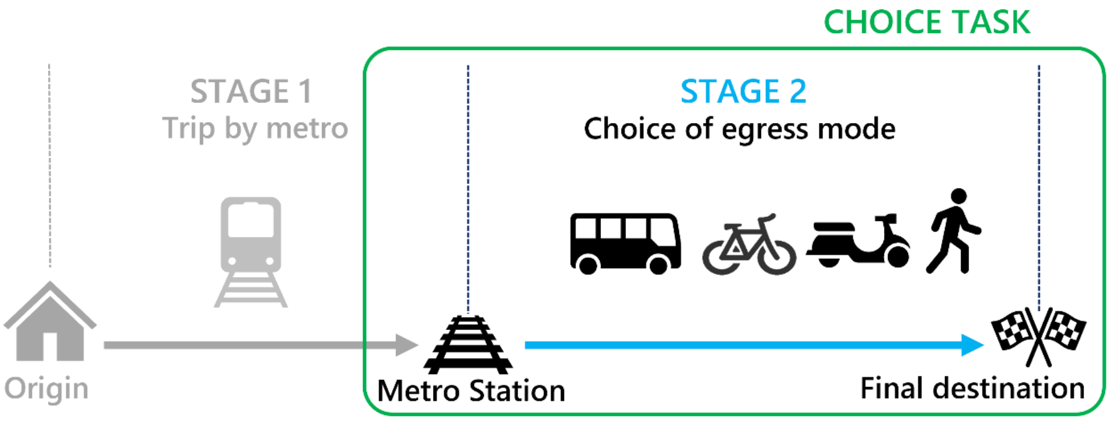

Figure 13. Choice task explanation: Egress mode choice (step 1)

The second transport mode decision (step 2), assumes the overarching mode choice situation before deciding whether or not to travel by train. In this case, the whole trip chain is considered (see Figure 14). The alternative chosen in the egress mode task will represent a multimodal option together with the metro (it is already known that is the preferred combination for the respondent). The other options presented are unimodal alternatives against which such a multimodal alternative competes. This choice task aims to capture the improvement (*if any*) that the presence of shared modes integrated with metro, can represent for the attractiveness of the latter. By understanding such a relationship, it is argued that some of the potential of the integration between PT and shared modes might be evaluated. Furthermore, it also allows to estimate competition of metro and shared modes, as shared modes can be included as separate alternatives for the whole trip, hence analysing overall preferences of modes for long-distance trips. For the remainder of the report, this choice situation is called *complete trip mode choice*.

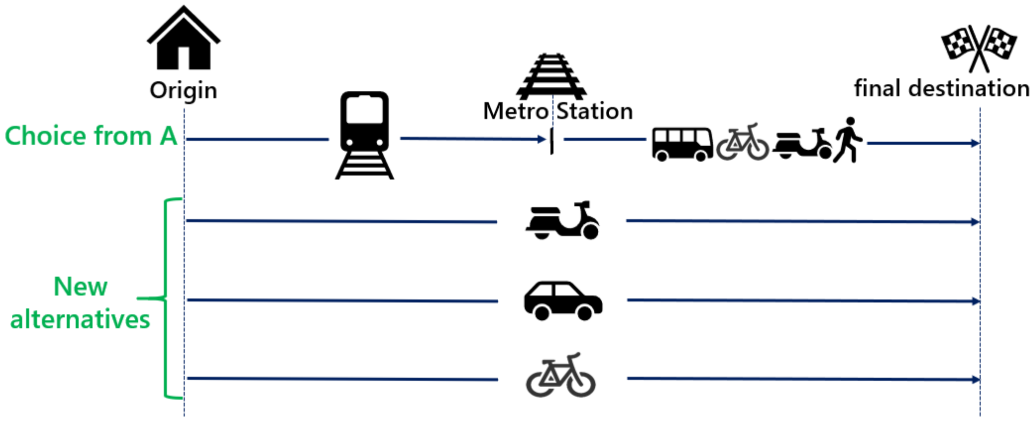

Figure 14. Choice task explanation: Complete trip mode choice (step 2)

5.1 Model specification

Following the differentiation between the two types of choice tasks, the next subsection describes in detail the stated preference survey design.

5.1.1 Alternatives

The investigated modes are *car, bike, metro, tram/bus, shared bicycle and shared moped*. Even though the choice set still seems rather large, the characteristics of each mode make each of them available and suitable for a certain type of trip rather than for all of them. The modes available within each of the tasks described before are presented in Table 5 below.

Table 5. Alternatives per choice situation

Mode / Choice situation	**Egress mode choice**	**Complete trip**
Metro (multimodal)		X [1]
Bus/tram	X	
Walk	X	
Bike		X
Car		X
Shared bicycle	X	
Shared moped	X	X

---

[1] Metro alternative is always combined with one of the alternatives defined for egress mode choice. Accordingly bus/tram, walk and shared bicycle are also included in the second set depending on the choices made in 1.

It is important to clarify that choice sets are subject to availability of modes for respondents, as well as their ability to drive/use specific modes. For instance if a respondent does not have a valid driving license, car and e-moped alternatives are not displayed.

5.1.2 Context

As discussed in chapter 2, several attributes affect mode choice. Considering the purpose of the study, it is decided to define the context of the experiment in function of some of them. The remaining ones represent the attributes of the alternatives, which are discussed further in subsection 5.1.3. The context of the experiment represents the assumptions under which choices are made. Different factors are defined to characterise it: *Trip purpose, user-friendliness, parking availability, shared modes scheme, day of the week, COVID-19, luggage,* and *weather.* Every respondent faces a single context that is kept fixed for all scenarios. While most factors are equal for all respondents, the **trip purpose** is varied randomly across the sample. For simplification, it is decided to include it only making a distinction between *commuter* and *non-commuter* trips. Besides, by including that distinction, one can argue that a relationship with time of day can be elucidated. For instance, commuter trips might be assumed to be mainly done during peak hours, while non-commuter trips would be expected to be mainly off-peak. The rest of the contextual factors are fixed to all respondents as defined, according to the following definition:

User-friendliness: It is assumed that shared modes and public transport are perfectly integrated. Accordingly, shared modes are assumed to be always available at metro stations, and the booking and payment of both PT and Shared modes are done using the same platform/system (*e.g. both are paid using OV-chipkaart).*

Parking availability: It is assumed that parking for shared modes and bike is always available. Furthermore, car parking is also available, even though it might come with a price, as it will be described later.

Shared modes scheme: Both shared bicycles and shared mopeds are assumed to be dockless. Hence, at the end of the rental period they can be left almost anywhere in the city[2]. Besides, given this ‘dockless’ assumption, in addition to metro stations they can also be found in different locations around the city.

Day of week: It is assumed that the trips are done during week-days. As mentioned in 3.3, previous studies performed by RET suggest higher levels of shared modes use are during these days compared to weekends.

COVID-19: It is assumed that COVID-19 no longer possess a risk.

Luggage: It is assumed that the trips do not involve carrying heavy or big luggage.

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[2] For dock-less services there are usually areas in which vehicles can be left. For the study case, this areas are many and easily found around the city. Hence, the Parking availability assumption.

Weather: Use of shared modes is expected to be highly dependent on good weather conditions. Hence, it is assumed that weather conditions are favourable: dry conditions and a temperature that does not represent a reason not to walk, ride a bicycle or ride a moped.

5.1.3 Attributes

The attributes of each alternative represent the characteristics of the trip depending on the properties of each mode. The attributes included in this study are based on different studies: (Arendsen, 2019; Arentze & Molin, 2013; Limburg, 2021; van Kuijk et al., 2021), and on the objectives and scope of this project. It is decided to include cost and time attributes, taking into account the distinction of their different components. The overview of the attributes included per alternative in tasks of egress mode choice is displayed in Table 6 below.

Table 6. Overview of attributes per alternative – Egress mode choice

Attributes / Alternatives	**Bus/Tram**	**Shared bike**	**Shared moped**	**Walking**
Waiting Time	X			
In-vehicle time	X	X	X	
Walking time to destination	X			X
Searching time			X	
Travel cost		X	X	

For the complete trip mode choice, the overview of the attributes is depicted in Table 7. It is important to keep in mind that this choice situation is performed immediately after the choice situation for egress mode. In this case, the alternative '*Multimodal trip*', represents a trip chain including the metro trip and the choice made for the egress leg (previous question). Accordingly, the attributes vary depending on the choices made.

Table 7. Overview of attributes per alternative - Complete trip mode choice

Attributes / Alternatives	**Multimodal trip**		**Bike**	**Shared moped**	**Car**
	Metro	**Egress**			
Waiting Time	X				
In-vehicle time	X	*Same as in egress mode choice (see Table 6)*[3]	X	X	X
Walking time to destination					X
Searching time				X	
Travel cost	X			X	X
Parking Cost					X

---

[3] The attributes included in the egress part of the multimodal trip alternative depend on the choice made for the egress leg

5.2 Experimental Design

The experimental design defines how alternatives and attributes are organized to form choice tasks. Such a design is obtained by varying different attribute levels systematically so that reliable and significant parameters can be estimated from the experiment (Ortuzar & Willumsen, 2011). It is intended that each choice task provides as much information as possible regarding trade-offs and user preferences. The experimental design is obtained using the software *Ngene* (Choicemetrics, 2018).

5.2.1 Type of design

Labelled experiment

Given the purpose of the study, it is decided to use labelled alternatives. Contrary to un-labelled experiments, this type of design allows the modeller to specify attributes that are alternative specific. As different modes are being investigated, this design also enables the capture of preferences that are related to a particular mode.

D-efficient design

Efficient designs aim to result in data that produces parameters as significant as possible. These types of design allow for the optimisation of choice tasks so that they provide as much information as possible (Choicemetrics, 2018). Since similar studies have been made in recent years in the Netherlands, it is possible to obtain reliable priors. As a result, it is possible to generate a *D-efficient* design that outperforms non-efficient designs (Walker et al., 2018).

5.2.2 Attribute Levels

Attribute Levels are determined considering different OD combinations within the Rotterdam region and computing respective attributes per each alternative for each of those trips. To determine travel times, the most popular trip-planning apps are used: *Google Maps* (*Google Maps*, 2021), *9292* (9292, 2021) and *RET planner app* (*Optimaal OV - RET*, 2021). Regarding costs, information available in the webpages of RET and shared mobility providers are used as a basis (*Check.*, 2021; *Felyx - Beat the Streets*, 2021; *Optimaal OV - RET*, 2021; Donkey Republic, n.d.; GO Sharing, 2021; Mobike, 2021; OV-fiets, 2021). An overview of pricing schemes applicable to the case study is presented in Table 8.

Table 8. Price schemes of relevant transport modes

Transport Mode	Price
Bus / Tram / Metro	€0.99 basic fare + €0.151/km
Shared bicycles	≈ €1.50 - €1.70 < 20 min
	≈ €2.20 - €3.00 < 30 min
	≈ €3.00 - €3.30 < 40 min
Shared mopeds	€0.25 - €0.30 / minute

The main idea behind the approach adopted is to obtain realistic values for the case at hand. To estimate the impact of possible pricing schemes and policies, the range of attributes is expanded beyond the range of current values. It is important to highlight that as recommended in Choicemetrics (2018) and Walker et al. (2018), attribute levels are equidistant. Moreover, three levels are included per attribute to be able to evaluate non-linear relationships. The attribute levels varied during the experiment of egress mode choice are presented in Table 9, with the levels associated with the complete trip being shown in Table 10.

Table 9. Attribute levels – Egress mode choice

Attribute / Alternative	Bus / Tram	Shared bicycle	Shared moped	Walking
Waiting time (min)	2, 5, 8	-	-	-
In-vehicle time (min)	5, 7, 9	7, 10, 13	5, 7, 9	-
Walking time (min)	1, 3, 5	-	-	12, 16, 20
Cost (€)	1.20, 1.70, 2.20	1.20, 1.70, 2.20	1.70, 2.20, 2.70	-

Table 10. Attribute levels – Complete trip mode choice

Attribute / Alternative	Metro[4]	Bike	Shared moped	Car
Waiting time (min)	1, 3, 5	-	-	-
In-vehicle time (min)	10, 15, 20	20, 25, 30	15, 20, 25	20, 25, 30
Walking time (min)	-	-	-	1, 3, 5
Searching time (min)	-	-	1, 3, 5	-
Travel cost (€)	1.80, 2.40, 3.00	-	4.00, 5.00, 6.00	2.00, 4.00, 6.00
Parking Cost (€)	-	-	-	0.00, 5.00, 10.00

5.2.3 Priors

Using a *D-efficient design*, it is necessary to determine parameter priors. The efficiency of the design relies on the reliability of said values. The closer they are to the true parameters of the population, the more efficient the design is (Choicemetrics, 2018; Walker et al., 2018).

Priors are determined considering three previous studies. The basis is the study performed by Arentze & Molin (2013), in which different stated choice experiments were conducted to understand mode preferences in multimodal networks. It includes specifications for single-mode trips as well as multimodal PT trips, for which differentiations were made between the different trip legs (*i.e. access, main leg, egress*). Despite the close relationship between that study and this research, it does not provide all the necessary information. Accordingly, two other studies are considered (Arendsen, 2019; van Kuijk et al., 2021). Given the different model specifications in the three studies, the priors taken from Arendsen (2019) and van Kuijk et al. (2021) are scaled to maintain consistency with the priors from

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[4] In addition to the attributes of the metro, this option also includes attributes of the selected egress mode.

Arentze & Molin (2013). To scale the priors, common parameters between studies are found, and their ratio is used as a correction factor. The process can be better visualized with the flow diagram displayed in Figure 15. In case it is not possible to find a prior parameter, a prior from a similar parameter is used.

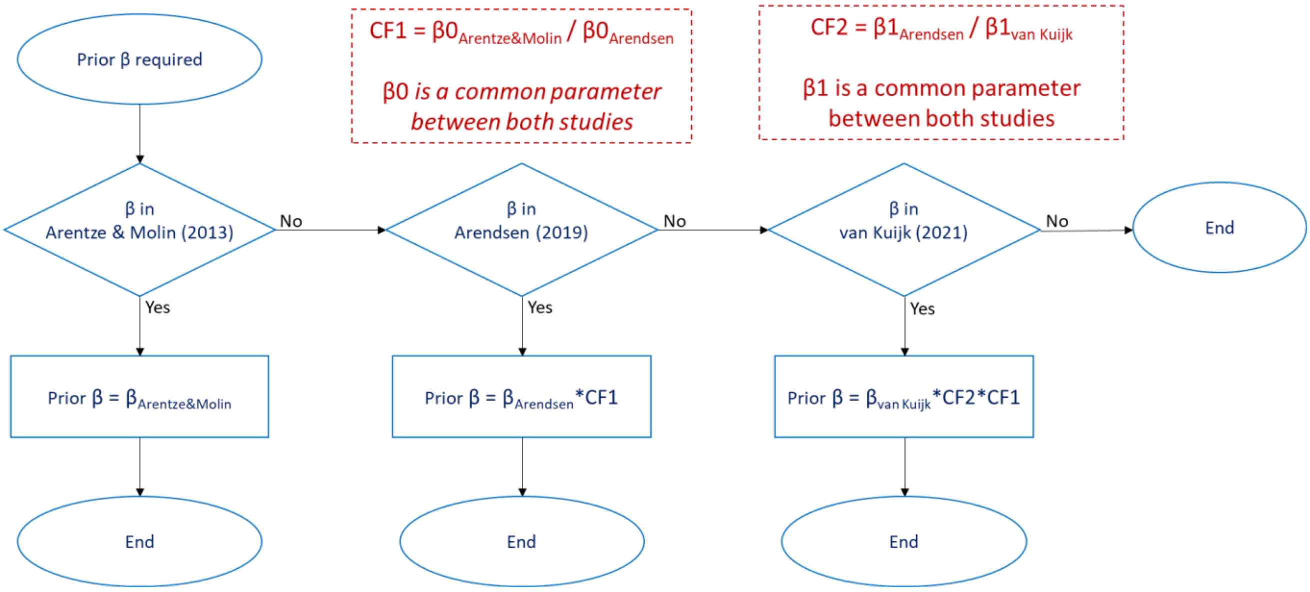


Figure 15. Flow Diagram - Scaling Prior parameters

The parameter priors are specified per choice task. The priors specified for the egress mode choice are depicted in Table 11 while the ones for the complete trip are in Table 12. Note that in both tables the first row has prior values for Alternative specific constants (ASC). Such values represent the expected utility of each alternative if all the other attributes were to be equal to zero.

Table 11. Prior parameters – egress mode choice

Prior / Alternative	**Bus/tram**	**Shared bicycle**	**Shared moped**	**Walking**
ASC	0.146	-0.804	-1.802	0.000
Waiting time (min)	-0.112			
In-vehicle time (min)	-0.069	-0.051	-0.072	
Walking time (min)	-0.168			-0.101
Cost (€)	-0.207	-0.432	-0.798	

Table 12. Prior parameters-complete trip mode choice

Prior / Alternative	Metro	Bike	Shared moped	Car
ASC	-0.85	-0.741	-2.69	0
Waiting time (min)	-0.0738		-	-
In-vehicle time (min)	-0.06	-0.076	-0.06	-0.079
Walking time (min)	-	-	-	-0.101
Searching time (min)	-	-	-0.023	-
Travel cost (€)	-0.207	-	-0.798	-0.098
Parking Cost (€)	-	-	-	-0.178

5.2.4 Number of choice situations

One of the main advantages of using efficient designs is the possibility to define the number of choice situations. Since all the attributes are varied in three levels and considering that attribute level balance is usually desired, it is fixed to a number divisible by 3. It is important to remember that for each choice situation, respondents answer 2 questions, thus the real number of choice tasks is twice the number of situations. After exploring different numbers of choice situations, the number is set to 9. This value yields a design expected to provide significant parameters with a reasonable number of respondents. Moreover, it is expected to result in an experiment reasonable in terms of time and effort required from respondents. Nonetheless, this is tested later in the pilot survey.

5.2.5 Final experimental design

As mentioned before, the SC experiment was designed using the specialised software *Ngene*. The syntax used to generate the designs can be found in Appendix A.1. The experimental design yields as a result a matrix filled with the levels per attribute for each choice situation. The experimental designs for egress and complete trip mode choice are presented in Appendix A.2. By default, *Ngene* aims for attribute level balanced designs. Nonetheless, as it can be noticed for the complete trip mode choice it was not possible to maintain this property. As an alternative solution, all attributes were forced to have each level at least twice.

5.3 Questionnaire

Finally, a survey is designed using the online tool *Qualtrics*. The largest part of the survey is a questionnaire constructed from the determined experimental designs (*SC experiment*). In addition it also includes an introductory section, questions regarding the respondents' socio-demographics and transport-related questions. The outline of the survey is presented in Figure 16. The complete final version of the survey presented to respondents can be found in Appendix A.3.

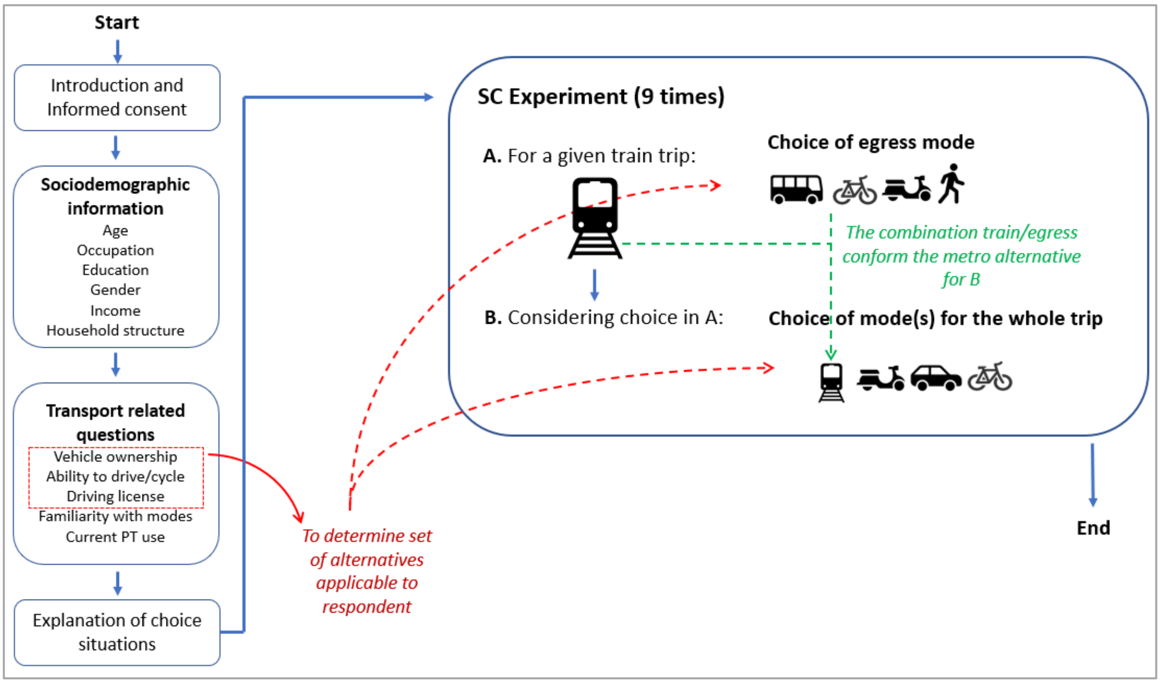


Figure 16. Survey Outline

Sociodemographic information

In addition to the context and attributes included in the SC experiment, the literature reviewed suggests that other factors might have relevance for the preferences exhibited by respondents: *sociodemographic characteristics.* Even though they are independent of the experimental design, by including them in the survey, it could be later evaluated whether they have a statistically significant relationship with mode choices exhibited by respondents. An overview of the sociodemographic information collected in the survey is presented in Table 13. In addition to the options displayed in the Table, respondents also can indicate that they prefer not to answer each sociodemographic question.

Table 13. Sociodemographic information included in the survey

Sociodemographic characteristic	Options
Gender	Male Female Non-binary
Age	18-25 years of age 26-35 years of age 36-45 years of age 46-55 years of age 56-65 years of age 66-75 years of age >75 years of age
Occupation	Full-time worker Part-time worker Student Voluntary worker Neither studying nor working Retired
Highest completed level of education	High School (vocational) - VMBO (MAVO) High School (applied sciences) - HAVO High School (theoretical) - VWO Vocational Education - MBO Bachelor Master Other (asked to specify)
Number of people (including respondent) in the household	1 person 2 people 3 people >3 people
Gross annual income	<€10.000 €10.000 - €30.000 €30.000 - €50.000 €50.000 - €100.000 €100.000 - €200.000 >€200.000

Transport related questions

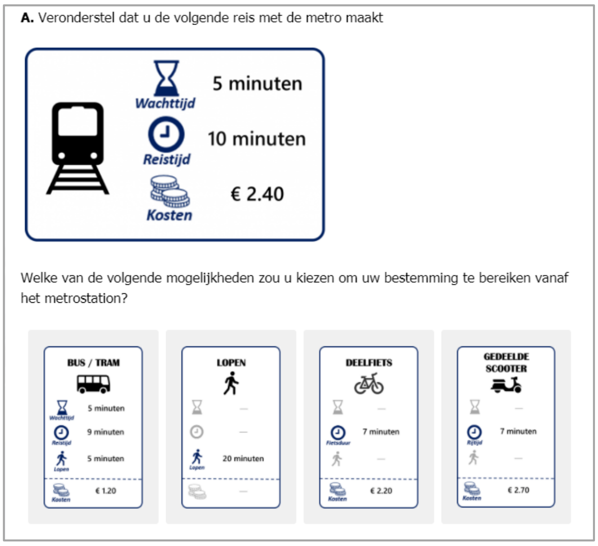
This section has two objectives. First, to understand current use of Public transport of respondents and their familiarity with shared bicycles and shared mopeds. Second, to define the range of modes that is relevant for each person. The former can be used to evaluate possible correlations with the behaviour stated by respondents. The latter on the other hand, allows to filter transport options, so respondents are only shown the alternatives available in reality for them. The information asked in these questions and the options included are depicted in Table 14. Analogously to the sociodemographic questions, for each transport related question respondents have also the option of not answering.

Table 14. Transport related questions

Characteristic	Options
Frequency of Public transport use	<1 days a week 1-2 days a week 3-4 days a week 5 days a week
Ability to ride a bicycle	Yes No
Availability of a bicycle	Yes No
Possession of driving license to drive a car (type B)	Yes No
Possession of driving license to drive a motorcycle (type A)	Yes No
Availability of a car	Yes No
Familiarity with shared bicycles and shared mopeds	Familiar with both concepts Only familiar with shared bicycles Only familiar with shared mopeds Not familiar with either
Having used a shared bicycle or a shared moped	Yes No

Stated Choice experiment

After the explanation of the experiment, respondents are presented 9 different choice situations, each of which involves two questions. All respondents face the same situations that are derived from the experimental design. However, depending on the range of vehicles available to each person, the set of alternatives might vary. An example of the egress mode choice task (question A) is displayed in Figure 17. Example of egress mode choice - choice situation 1. It is assumed a respondent with all modes available, and the attribute levels are those from choice situation 1 (see Appendix A.2).



A. Veronderstel dat u de volgende reis met de metro maakt

Welke van de volgende mogelijkheden zou u kiezen om uw bestemming te bereiken vanaf het metrostation?

Figure 17. Example of egress mode choice - choice situation 1

Immediately after Question A is answered, the complete trip mode choice task (Question B) is presented. The alternatives displayed depend not only on the range of modes available but also on the decision made in question A. For that same respondent, and assuming that the option *'Bus/Tram'* is selected as egress mode, question B in choice situation 1 would look like it is shown in Figure 18.

B. Neem nu de hele reis van uw huis naar uw eindbestemming in beschouwing. Welke van de volgende mogelijkheden zou u kiezen?

Figure 18. Example of complete trip mode choice – choice set 1

5.4 Pilot

Before launching the final version of the survey, a pilot survey is conducted. The main objectives of the pilot are to verify if the tasks are understandable, to check the quality of the experimental design, to observe the completion time and to check display logic. The pilot was accessed by 41 people, 31 of whom completed it.

Understandability of tasks

To know whether respondents understand the survey, the pilot is distributed among both people familiar and people unfamiliar with these kinds of experiments. They are asked to provide feedback by email, especially in case something is wrong or unclear. The overall opinion suggests that tasks are clear on their own and that the explanation of tasks strengthens their understanding. However, there are some suggestions regarding the elimination of some text, and improving writing style in other parts. The suggestions that are considered relevant, are adopted to improve the survey.

Quality of experimental design

The quality of the experimental design is judged based on variation in answers per choice task between respondents, and in terms of choices by a single respondent. The former to evaluate possible dominance of alternatives, while the latter to look at the importance of alternative specific constants (ASC). While there is a certain level of dominance of alternatives in some choice tasks, there is still sufficient variation of responses (see Figure 19 for overview of results). Moreover, respondents do not always choose the same alternative, which might suggest that not only ASCs are important, but also the variation of attribute levels (see Figure 20 for portfolio of alternatives per respondent). In concordance with the results, it is decided to keep the experimental design for the final survey.

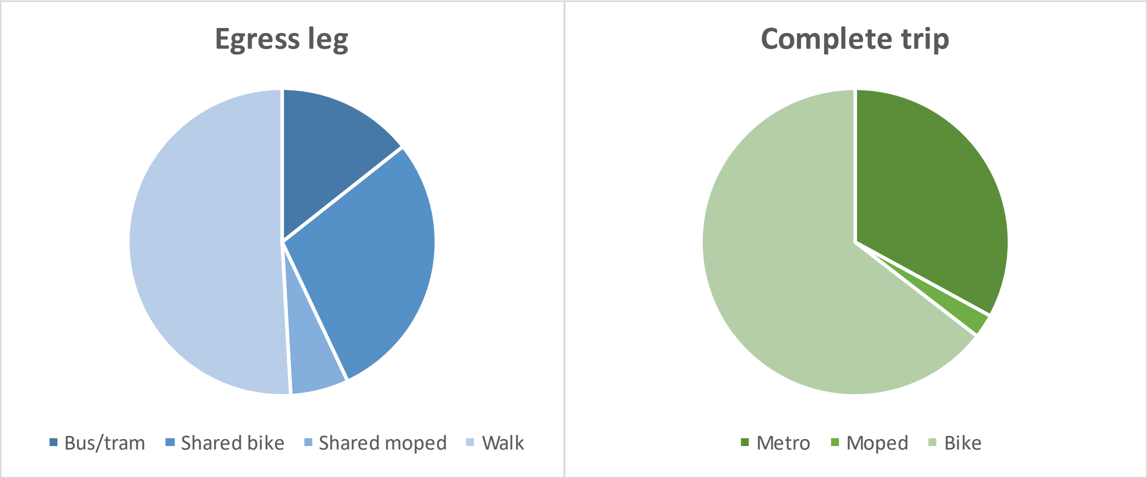


Figure 19. Choice overview in Pilot survey for both choice tasks (for complete trip mode choice no distinction is made among the four possible alternatives: *metro and bus/tram*, *metro and shared bike*, *metro and shared moped*, *only metro*)

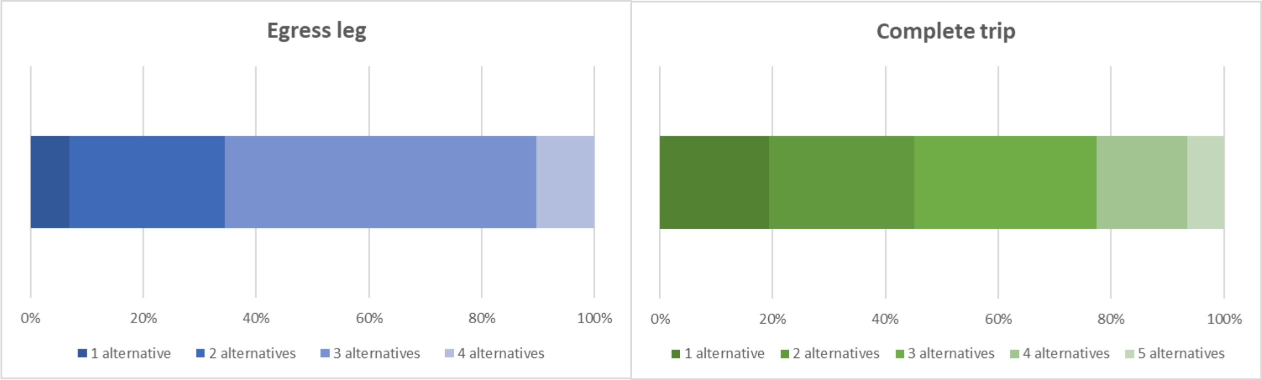


Figure 20. Size of portfolio in Pilot survey for both choice tasks (number of alternatives varied per individual)

Completion time

The distribution of completion time in the Pilot survey is presented in Figure 21. The average completion time was 16 minutes. However, there were some extreme values of 56 and 5 minutes for example, both of which seem unrealistic times for the survey. If extreme values are removed, the average falls to around 14 minutes. On the other hand, the median and mode are both 12 minutes. Accordingly, it can be concluded that normal completion times should be between 10 and 15 minutes, which seems an appropriate duration.

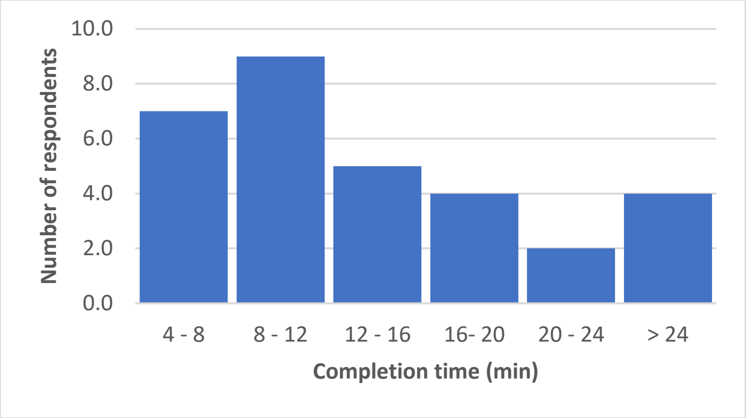


Figure 21. Distribution of completion time for Pilot survey

Display logic

An important property of this survey is the filtering of alternatives according to the realistic choice set available to each respondent. This is achieved by adding specific display rules to the alternatives in each question. To check that the display logic works properly, respondents are asked to report if any mistake is found. Furthermore, it is checked from the data collected whether the alternatives displayed were correct for each respondent. No problems are found in this regard. Nonetheless, some respondents report that the display order of alternatives might induce bias, reason why it is decided to randomize it in each question for the final Survey. Moreover, a comment was received that suggested that the attractiveness of metro alternatives consistently decrease over the survey as a result of the cost. As a response to that, the order of choice situations was manually re-arranged to avoid the issue.

5.5 Data Collection

After the feedback from the Pilot is processed and applied, the next step is to distribute the final version of the survey and to collect the data to be analysed. Before distributing the survey, it is translated to Dutch. The distribution is performed using an online panel: *PanelClix*. This online panel is then responsible for the distribution of the survey, given certain requirements in terms of the characteristics of the respondents that are desired according to the objectives of the study. Since transport mode choices seem applicable to most of the population, the only hard constraint applied to the sample is the need for people living in Rotterdam. The latter is decided, given that the characteristics of the city and its transport network are expected to play an important part in respondents' preferences (see Chapter 2).

The survey was accessed by 625 people, of which 525 were completed. The sample was then filtered based on the total response time and variability of the answers given. After the process, a total of 487 responses were considered valid, and thus were the ones included in the analysis to be further described in Chapters 6 and 7.

6 Descriptive statistics

In this Chapter, a range of descriptive statistics is presented. First, the main characteristics of the sample are presented. For some of those characteristics, a comparison is made against those same characteristics in the total population in Rotterdam. Then, different statistics are discussed to try to understand the overall preferences exhibited by respondents in the survey.

6.1 Sample characteristics

In this section, the most important characteristics of the sample are presented. It includes an analysis in terms of sociodemographic information in subsection 6.1.1, and transport-related information in subsection 6.1.2.

6.1.1 Sociodemographic information

The composition of the sample in function of sociodemographic characteristics is presented in Table 15. As mentioned before, the sample is conformed only by inhabitants of Rotterdam. Accordingly, its composition is compared to the one of the city, using official statistics available in (Centraal Bureau voor de Statistiek, 2021). From the comparison, some important things are noticed. Firstly, there is a relevant difference in gender distribution, while women accounted for 51% of the population of the city in 2020, they represent 59% of the sample. Secondly, in terms of age distribution, the sample closely represents the proportion of middle-aged groups (26 to 55 years old). They add up to 51% of the sample, which is only 2 percentage points lower than what was recorded for Rotterdam in the year 2020. On the other hand, the youngest and oldest segments (18-25 and >75 years old respectively) are under-represented (about half in proportion), while the proportion in the sample of people from 56 to 75 years of age is around 50% higher than that of the total population in the city. Finally, the sample is distributed rather similarly to the total population of the city in terms of the level of education.

Table 15. Sample composition in terms of sociodemographic information – Comparison with population of Rotterdam (Centraal Bureau voor de Statistiek, 2021)

Characteristic	Categories	Sample	Rotterdam (CBS, 2020)
Gender	Male	41%	49%
	Female	59%	51%
	Prefer not to answer	0%	-
Age	18-25	7%	15%
	26-35	18%	21%
	36-45	17%	16%
	46-55	16%	16%
	56-65	21%	14%
	66-75	16%	10%
	>75	4%	8%
	Prefer not to say	0%	-
Education	VMBO (MAVO)	15%	12%
	HAVO/ VWO / MBO	42%	45%
	Bachelor	24%	21%
	Master	13%	12%
	Other	4%	9%
	Prefer not to say	1%	-
Household	1 person	33%	48%
	2 people	40%	52%
	3 people	11%	
	More than 3 people	15%	
Income	< €10.000	4%	14%
	€10.000 - €30.000	28%	37%
	€30.000 - €50.000	26%	23%
	€50.000 - €100.000	19%	21%
	€100.000 - €200.000	2%	4%
	> €200.000	0%	1%
	Prefer not to say	20%	-

6.1.2 Transport related information

In order to be able to interpret the results properly, it is important to first understand the characteristics of the respondents with respect to their use of the different transport modes as well as their awareness of shared alternatives. This transport-related information is depicted in Table 16. As it can be observed, nearly three-quarters of the sample travel either two or fewer days a week by PT. In terms of familiarity with shared modes, over 20% of the sample are not familiar at all with either shared modes or shared moped, which strikes as surprising considering the number of vehicles and operators available within the city. Nonetheless, similar studies have also found high percentages of unfamiliarity with shared bicycles and shared mopeds. For instance, in a study of the potential use of on-demand services for urban mobility within the Netherlands, Geržinič et al. (2021) report that 17% of the participants in their survey had never heard of shared bicycles/mopeds. Arendsen (2019) on the other hand reports that 14% of the sample of his study had never heard of shared bicycles. Regarding the use of shared modes, 80% of participants in this study claimed having never used either a shared bicycle or a shared moped. This figure is in between of those found in Arendsen (2019) and Geržinič et al. (2021), which found values in this regard of 72% and 90% respectively. Note however that the former explicitly refers to previous use of shared bicycles, as shared mopeds were not included in the study.

Table 16. Overview of transport-related information in the sample

Characteristic	Categories	# of Resp.	%
Frequency of use of public transport	< 1 day a week	219	45%
	1-2 days a week	135	28%
	3-4 days a week	75	15%
	>= 5 days a week	50	10%
	Prefer not to say	8	2%
Familiarity with shared modes	Familiar with shared bikes and shared mopeds	307	63%
	Only familiar with shared bikes	25	5%
	Only familiar with shared mopeds	42	9%
	Not familiar with either shared mode	108	22%
	Prefer not to say	5	1%
Previous use of shared bicycles or shared mopeds	Yes	94	19%
	No	392	81%
	Prefer not to say	1	0%
Ability to ride a bicycle	Yes	433	89%
	No	51	10%
	Prefer not to say	3	1%
Bicycle availability	Yes	373	77%
	No	109	22%
	Prefer not to say	5	1%
Possession of valid driving license	Both type B[5] and type A[6]	82	17%
	Only type B	299	61%
	Only type A	3	1%
	Neither type B nor A	102	21%
	Prefer not to say	1	0%
Car availability	Yes	345	71%
	No	140	29%
	Prefer not to say	2	0%

In addition to information about awareness and use of transport alternatives, the table also reports the availability of certain modes and the ability of respondents to drive them. Concerning the former, it strikes as surprising the high proportion (22%) of respondents that do not have a bicycle available. Remember that The Netherlands is a country that accommodates more bicycles than people, and in which 84% of the population owned at least one bicycle in 2018 (Bicycle Dutch, 2018). Similarly, the percentage of respondents that cannot drive a bicycle is also rather high. After exploring the socio-demographics of the groups that exhibit such surprising features, it is noticed that their composition is

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[5] Driving license required in order to be able to drive an automobile

[6] Driving license required in order to be able to drive a motorcycle

characterised by considerable higher proportions of certain socio-demographic groups than those of the total sample. For instance, the proportions of people over 56 years of age in the groups unable to ride a bicycle and without a bicycle available are respectively 70% and 51%, while said percentage in the overall sample is only 40%. Something similar occurs with the gender distribution of those groups, 73% of respondents that claimed not being able to ride a bicycle and 69% of those who do not possess a bicycle are women, which exceeds the fraction of women in the sample in 14% and 10% respectively. Finally, both groups have also an over-representation of people with gross annual incomes below €30,000, with a surplus of around 15%. Note however that even though the information presented might suggest that there is possibly a correlation between these features and not having a bicycle or not being able to ride one, this cannot be concluded with certainty.

As explained in detail in section 5.3, some of the transport-related information collected in the survey is used to define the range of modes available to each participant in the survey. While everyone is assumed to have available the options of choosing public transport modes and walking, the remaining modes are only available under certain conditions that respondents need to meet: *possession of a driving license for car and shared moped, ownership of the respective vehicle for car and bicycle, and ability to ride the vehicle for bicycle and shared bicycle.* Accordingly, not all modes are available to everyone in the survey. The percentages of respondents that have available each of the transport modes subject to the mentioned conditions are displayed in Figure 22.

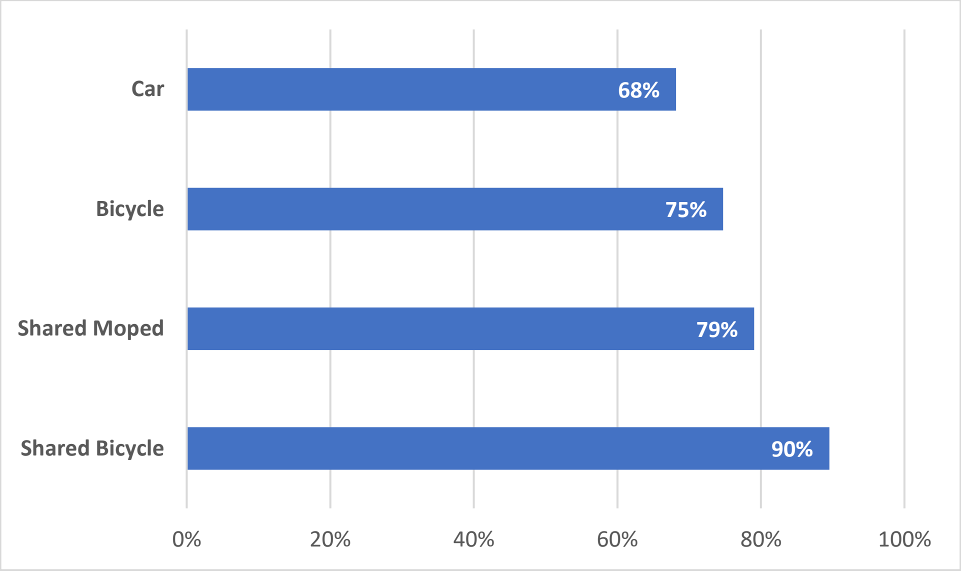

Figure 22. Availability of modes in the sample (PT modes and walking available for all respondents)

Because not all modes are available to everyone, the composition of the choice set varies among respondents. While some respondents only can choose from PT alternatives and walking, some might have only a couple more and some others could have all seven alternatives at their disposal. Figure 23 shows the distribution of possible choice sets across the sample. The modes included in the graph are extra modes added to public transport and walking, which every respondent has in their choice set. Note that more than half of the sample has all the alternatives in their choice set, and 97% have at least one shared mode at their disposal.

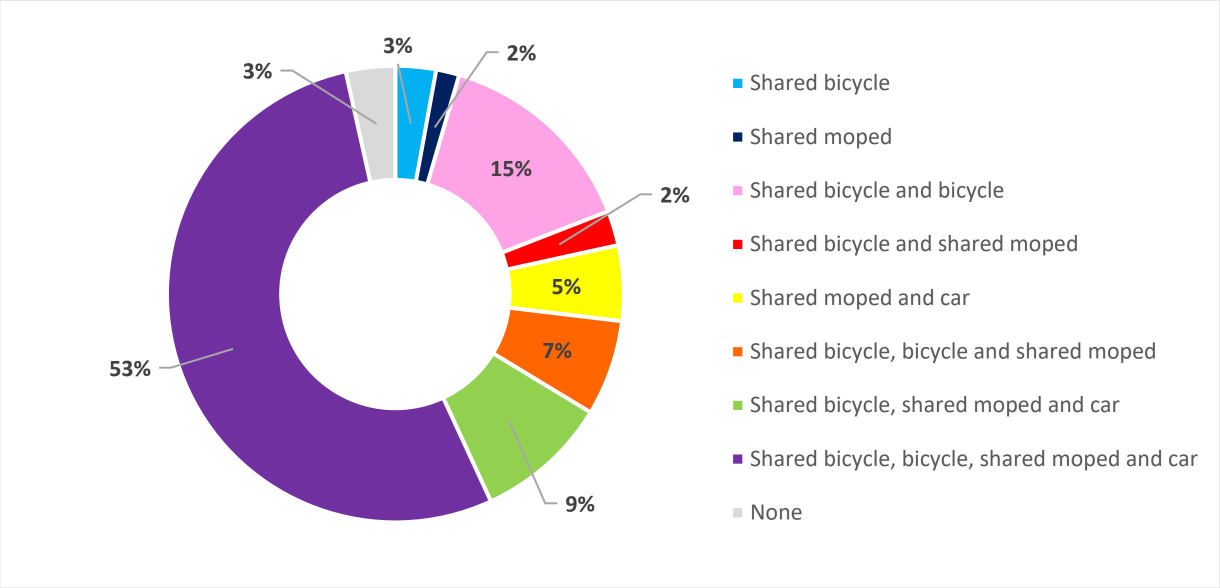

Figure 23. Overview of choice set composition (in addition to PT modes and walking)

The decision of accounting for the availability of alternatives per respondent answers to the aim of reproducing situations as close to reality as possible for respondents. However, the information presented in Figure 22 and Figure 23 must be taken into account in the analysis of choices to be presented in the remaining of this section.

6.2 Choice overview

Aside from the distribution of the sample in terms of their sociodemographic and transport-related characteristics, it is also considered important to do a general examination of their choices. By doing this, some mode preferences can be already noticed. Note however that in this part of the data analysis, the effects of the variation of attributes among transport modes are not considered. Despite aiming for an experiment as close as possible to real-life choice situations, that is not always possible. Hence, for some scenarios, the variation of attributes might have played a very important role in choices, which is not yet captured in this overview. In Figure 24 an outline of the preferences exhibited for the egress mode choice is presented. It is observed a clear tendency towards walking and PT, being the latter in this case represented by the bus/tram option. Nevertheless, shared modes account for a quarter of the total of choices for egress mode, even when they are not available for everyone. The latter might be argued to suggest certain potential of these modes to cover last-mile of multimodal trips with metro as the main mode.

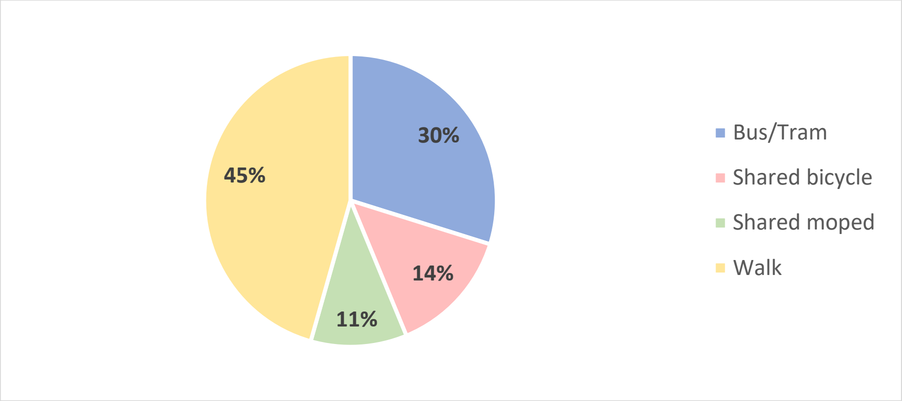

Figure 24. Choice overview – egress mode choice

In Figure 25 an outline of the preferences exhibited for the complete trip mode choice is presented. As noticed, half of the choices are for privately owned vehicles (*i.e. car and bike*), whereas the other half is distributed between metro combinations and shared moped. It strikes as interesting the high shared of metro choices, especially considering the rather low proportion of frequent PT travellers within the sample. Besides, by being chosen almost once for every ten tasks, shared mopeds seem to be an alternative for long-distance trips, and not only for short trips (including access and egress to and from PT respectively). Note that the distribution of egress modes when metro is chosen varies compared to the overall distribution presented in Figure 24. According to the results, metro seems to be chosen more often for the complete trip when it is combined with bus/tram as egress mode, rather than when egress is done walking. Furthermore, the proportion of shared modes as egress alternatives decreases compared to the overall distribution. The latter could be influenced by potential strong preferences towards PT of some respondents (‘*PT-lovers*’).

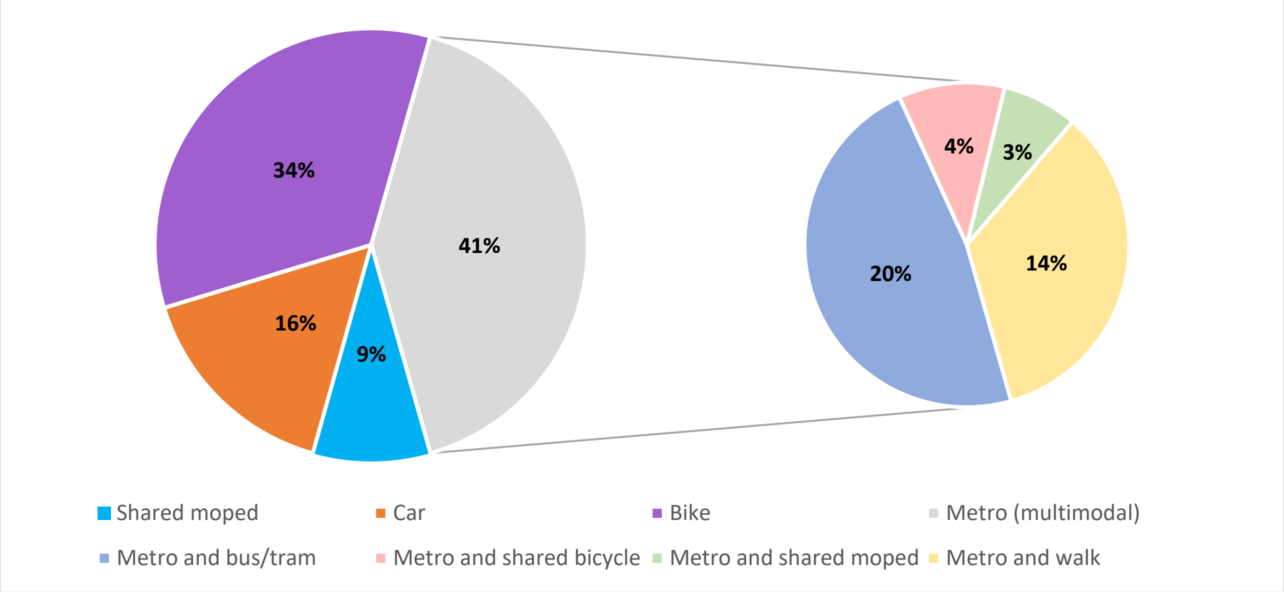

Figure 25. Choice overview – Complete trip mode choice

6.3 Portfolio of alternatives

To analyse the range of alternatives each respondent varied during the experiment, a portfolio of alternatives is generated for each part of the mode choice experiment. Despite the similarities with Figure 23, these graphs are different in the sense that they aggregate respondents not only in terms of alternatives available but also considering those that they chose at least once. Figure 26 presents the modal portfolios for the egress mode choice. Note that for all modes, some respondents always chose the same alternative (*non-traders*). The proportion of respondents that only chose bus/tram and walking is rather high compared to other modes. Even though this suggests strong preferences towards these egress modes, it is important to remember that as described in 6.1.2, they are the only alternatives available to every respondent, hence some did not have another choice but to hold to them. It is also interesting to notice that despite being fairly small, there is still a fraction of the respondents that consistently chose shared modes. This might suggest that just as it happens with other modes, there are some people with a strong preference towards shared modes (*shared modes lovers)*. Hence, one could argue that shared alternatives can become the preferred mode choice on a regular basis for certain people. Furthermore, it can be noticed that more than half the respondents chose at least once a shared mode. The latter is a very important insight as it shows that a considerable number of people might consider these modes as egress solutions.

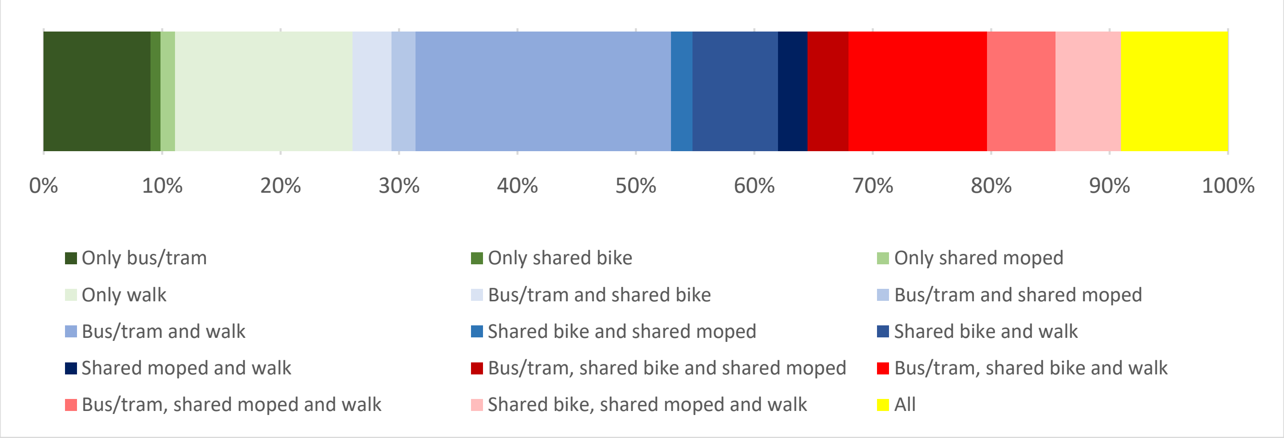

Figure 26. Portfolios of alternatives – Egress mode choice

Similarly, Figure 27 displays the modal portfolios for the complete trip mode choice. Notice that there are *non-traders* for all modes but shared moped. In concordance with that, it can be argued that according to the survey there are no strong *shared moped lovers* that always chose it without regard of how convenient or inconvenient it is in terms of travel time and cost. The choices towards this mode would be expected to partially respond to benefits for users such as travel time or economic savings. Besides, consistent with the predominance of PT shown in Figure 25, metro appears as the most frequent choice. Hence, portfolios with the highest proportion always include this mode. It is interesting to note that for both choice situations almost 10% of respondents made use of all alternatives at least once and over 20% varied between three alternatives. This is expected to respond to the variation of attributes between alternatives in each choice situation, which varies the attractiveness of each alternative compared to the others.

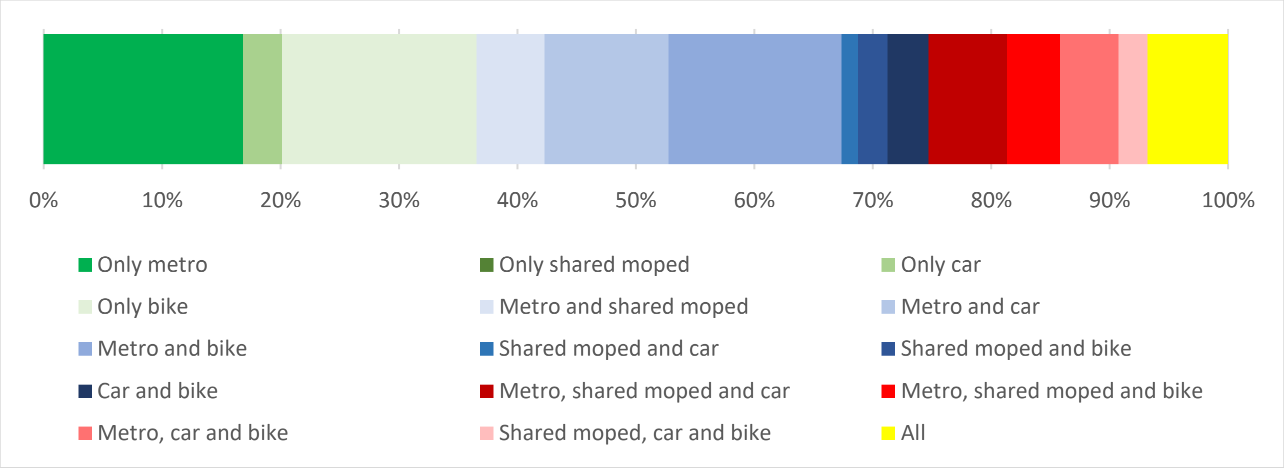

Figure 27. Portfolios of alternatives – Complete trip mode choice

To sum up, the portfolios of alternatives presented in this section show that even though public transport modes seem to dominate choices, shared bicycle and shared mopeds are both interesting transport alternatives for some groups of respondents. For the complete trip mode choice, it seems that choices towards shared moped are not based only on high preference towards the mode *('shared moped lovers')* but also on cost and/or time benefits. On the other hand, the fact that for the egress choice some *non-traders* consistently choose shared modes suggest that there might be an interesting market for them as regular egress alternatives.

7 Discrete choice modelling (DCM)

In this chapter, the discrete choice modelling part of the project is presented. Its objective is to understand and analyse how people make transport mode decisions. It weighs how different variables influence the choices recorded in the experiment. Two types of models are included in the study: Multinomial logit (MNL) and mixed logit (ML). For each of them, different models are estimated, each with specific aims that are further described in the remainder of this chapter. The estimation of the models is performed using *PandasBiogeme,* an open-source Python package specialised in the computation of DCM (Bierlaire, 2020). It is important to mention that all models are developed for the complete trip. By doing this, both choices per scenario (*i.e. egress mode choice* and *complete trip mode choice*) are included in one single model.

7.1 Multinomial logit model (MNL)

The first models estimated are MNL models. Between the two types of models included in the project, the MNL is the least demanding in terms of computation time. Several MNL models are estimated: first the general MNL model to be used as the base of the study, and then numerous variations of it to include interaction effects of sociodemographic characteristics. In subsections 7.1.1 and 7.1.2 the models and their respective results are discussed in detail.

7.1.1 MNL base model

This MNL model is defined as the base model for the study. Hence, all subsequent models are built as a variation of this model in one or multiple aspects. To illustrate the parameters included, and how they are related to the different variables that characterise the alternatives, the utility functions for all modes are presented in equations 8-14 (the specification of each symbol included in the equations is presented in Table 17). Note that as ASC parameters are defined per each separate mode, multimodal options (e.g. metro and shared bike combination) have two ASC involved in their utilities. Although most of the parameters are generic, some are only applicable to a certain mode. Considering the outcomes of Arentze & Molin (2013), previously used to define the priors, a distinction is made between time and cost parameters for main and egress legs.

$$U_{metro\&bt} = ASC_{metro} + ASC_{bt} + \beta_{metroWait} * wt_{metro} + \beta_{mainTime} * vt_{metro} + \beta_{mainCost} * cost_{metro} + \beta_{egressTime} * (vt_{bt} + wt_{bt}) + \beta_{walk} * walk_{bt} + \beta_{egressCost} * cost_{bt} \tag{8}$$

$$U_{metro\&sb} = \mathrm{ASC}_{\mathrm{metro}} + \mathrm{ASC}_{\mathrm{sb}} + \beta_{\mathrm{metroWait}} * \mathrm{wt}_{\mathrm{metro}} + \beta_{\mathrm{mainTime}} * \mathrm{vt}_{\mathrm{metro}} + \beta_{\mathrm{mainCost}} * \mathrm{cost}_{\mathrm{metro}} + \beta_{\mathrm{egressTime}} * \mathrm{vt}_{\mathrm{sb}} + \beta_{\mathrm{egressCost}} * \mathrm{cost}_{\mathrm{sb}} + \varepsilon \tag{9}$$

$$U_{metro\&sm} = ASC_{metro} + ASC_{smE} + \beta_{\mathrm{metro}Wait} * wt_{metro} + \beta_{\mathrm{mainTime}} * vt_{metro} + \beta_{\mathrm{mainCost}} * cost_{metro} + \beta_{egressTime} * vt_{smE} + \beta_{egressCost} * cost_{smE} + \varepsilon \tag{10}$$

$$U_{metro} = ASC_{metro} + \beta_{metroWait} * wt_{metro} + \beta_{mainTime} * vt_{metro} + \beta_{mainCost} * cost_{metro} + \beta_{walk} * walk_{metro} + \varepsilon \quad (11)$$

$$U_{sm} = ASC_{sm} + \beta_{walk} * st_{sm} + \beta_{mainTime} * vt_{sm} + \beta_{mainCost} * cost_{sm} + \varepsilon \quad (12)$$

$$U_{car} = ASC_{car} + \beta_{walk} * wt_{car} + \beta_{mainTime} * vt_{car} + \beta_{mainCost} * (cost_{car} + parking) + \varepsilon \quad (13)$$

$$U_{bike} = ASC_{bike} + \beta_{mainTime} * vt_{bike} + \varepsilon \quad (14)$$

Table 17. Description of symbols used in utility equations

Symbol	Description
$\boldsymbol{U_{metro\&bt}}$	Utility of metro and bus/tram alternative
$\boldsymbol{U_{metro\&sb}}$	Utility of metro and shared bicycle alternative
$\boldsymbol{U_{metro\&sm}}$	Utility of metro and shared moped alternative
$\boldsymbol{U_{metro}}$	Utility of metro alternative
$\boldsymbol{U_{sm}}$	Utility of shared moped alternative
$\boldsymbol{U_{car}}$	Utility of car alternative
$\boldsymbol{U_{bike}}$	Utility of bicycle alternative
$\boldsymbol{ASC_{metro}}$	Alternative specific constant for metro
$\boldsymbol{ASC_{bt}}$	Alternative specific constant for bus/tram
$\boldsymbol{ASC_{sb}}$	Alternative specific constant for shared bicycle
$\boldsymbol{ASC_{smE}}$	Alternative specific constant for shared moped as egress mode
$\boldsymbol{ASC_{sm}}$	Alternative specific constant for shared moped as main mode
$\boldsymbol{ASC_{car}}$	Alternative specific constant for car
$\boldsymbol{ASC_{bike}}$	Alternative specific constant for bike
$\boldsymbol{\beta_{metroWait}}$	Parameter for waiting time for metro
$\boldsymbol{\beta_{mainTime}}$	Parameter for in-vehicle time in main mode
$\boldsymbol{\beta_{mainCost}}$	Parameter for cost of main mode
$\boldsymbol{\beta_{egressTime}}$	Parameter for in-vehicle time in egress mode
$\boldsymbol{\beta_{walk}}$	Parameter for walking time
$\boldsymbol{\beta_{egressCost}}$	Parameter for cost of egress mode
$\boldsymbol{wt_{metro}}$	Waiting time for metro
$\boldsymbol{vt_i}$	In vehicle time in mode *i*
$\boldsymbol{cost_i}$	Cost of mode *i*
$\boldsymbol{wt_i}$	Waiting time for mode *i*
$\boldsymbol{parking}$	Parking cost for car
$\boldsymbol{\varepsilon}$	Random component of the utility

It is important to mention that numerous different model specifications were tested, varying the number of parameters to be estimated as well as the utility definition derived from those changes. The specification presented in this chapter is the one that yielded the most satisfactory results in terms of the statistical significance of parameters (according to their *t-values*). Moreover, it also is characterised by a rather small number of parameters, which is expected to ease the model interpretability and to reduce computation times for the more complex models discussed in the following sections. Table 18 presents the results of the MNL base model.

Table 18. Parameter estimates – MNL base model (Rho-square =0.170)

Name	**Unit**	**Value**	**Rob. SE**	**Rob. t-test**
Alternative specific constants				
ASC_BIKE	utils	-0.275	0.107	-2.58
ASC_BT	utils	0.676	0.231	2.92
ASC_METRO	utils	-0.858	0.194	-4.41
ASC_SB	utils	-0.864	0.243	-3.56
ASC_SM	utils	-1.380	0.081	-17.00
ASC_SM_E	utils	-0.942	0.258	-3.66
ASC_CAR[7]	-	0.000	-	-
Cost parameters				
B_MAIN_COST	utils/€	-0.093	0.011	-8.68
B_EGRESS_COST	utils/€	-0.425	0.079	-5.37
Time parameters				
B_EGRESS_TIME	utils/min	-0.039	0.012	-3.25
B_MAIN_TIME	utils/min	-0.034	0.005	-6.64
B_METRO_WAIT	utils/min	-0.014	0.022	-0.65
B_WALK	utils/min	-0.064	0.010	-6.29

Legend: highlighted blue: significant at 99% confidence interval

Important to note that most of the parameters are statistically significant on a 99% confidence interval. The only parameter not significant is the one for waiting time: *B_METRO_WAIT*. From that, and according to the very low value (and the respective t-value) for *B_METRO_WAIT*, it can be argued that there is no strong evidence that the effect of waiting time for metro is different to *zero*, in other words, the results suggest that this attribute might not play a role in mode choice in the context of this study. Focusing only on the ASC parameters, some insights might be gained regarding mode preferences. It is noticed that on average car remains the most attractive option for users, yet bicycle and the combination metro and bus/tram seem to have similarly positive perceptions. Among the alternatives including shared modes, shared moped as an individual mode appears as the one with the better perception[8]. Considering that by definition these ASC represent the utility difference between alternatives assuming that all other variables are zero (or equal[9]), the probability of any of the seven alternatives being chosen can be computed. In Figure 22, a graphical representation of the choice probabilities in such a hypothetical scenario is presented. It is interesting to remark that in this hypothetical scenario alternatives including shared modes add up to about 1/8 of probability. Note however that in real-life cases differences in terms of travel time and travel cost among alternatives would be expected, which would affect substantially the choice probabilities.

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[7] ASC for all modes is relative to the one of car. Hence, ASC for car is fixed to zero.

[8] Remember that the base preference towards the multimodal alternatives combining metro and a shared egress alternative is defined by the sum of the two ASC. Given the negative sign and the magnitude of *ASC_METRO* the values for these alternatives is lower than that of share moped.

[9] Equal so that the remaining of the utility is the same

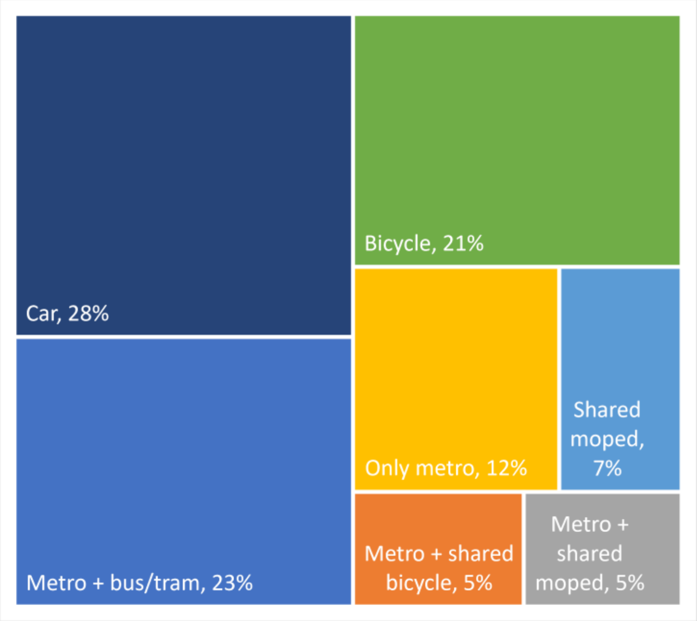

Figure 28. Choice proportions if only ASCs matter

In addition to ASC, also cost and time parameters are estimated. When comparing parameters for the egress leg against the ones for the main leg, two things can be noticed. First, on average people seem to be considerably more sensitive to egress cost than to main mode cost (almost five times). Contrastingly, in terms of times, parameter estimates for both trip legs are very similar, which suggests that there is not much difference in terms of sensitivity for travel time. Nonetheless, this only holds when travel times are done using a vehicle. In the case of walking time this changes, as the *B_WALK* parameter is almost twice the size of the other two time parameters already discussed. To conclude, according to the results it can be argued that the egress leg does not seem to be perceived negatively in terms of travel time but in terms of travel cost. For shared bicycles and shared mopeds as egress modes, it might suggest that they can benefit from offering travel time savings and from causing a decrease in walking distances. However, their prices should be thought carefully so as not to be a strong deterrent against their use.

7.1.2 MNL with interaction effects

As suggested by the literature review, different socio-demographic characteristics are also expected to influence choices. As a result, it is decided to use discrete choice modelling to evaluate the effects of said variables. As *trip purpos*e was varied by design in the SC experiment, its effects are also evaluated. Each characteristic is initially modelled separately to have a clearer estimation of its effects and relevance. Besides, for each characteristic, three different models are estimated, each evaluating effects on a different type of parameter: ASC, cost, and time.

Dummy coding is adopted as the method to include the interactions. Given the high number of categories per variable, it is decided to group each variable in either two or three distinct categories only. In Table 19 an outline of the division by categories of each variable is presented.

Table 19. Division by categories of variables for MNL with interaction effects

Variable	Categories	Base	1	2
Gender	2	Female	Male	-
Trip purpose	2	No Commute	Commute	-
Age	3	> 65 years of age	<= 35 years of age	35-65 years of age
PT-Use	3	< 1 time a week	1-4 times a week	>= 5 times a week
Familiarity with shared modes	2	No familiar	Familiar	-
Previous use of shared modes	2	No	Yes	-
Gross annual income	3	< €30.000	€30.000 - €50.000	> €50.000
Highest completed level of education	3	Below category 1	MBO - HAVO/VWO	HBO/WO, bachelor or higher

Dummy coding is used to estimate interaction effects, and it does so by taking a base category as a reference. The model gives an estimated parameter for that base category and shows how much the parameter varies for each of the other categories. The results obtained with the different models are presented in Appendix B.2. The Overview of model fit indicators on the other hand is presented in Table 20, where they are also compared with the corresponding indicators of the MNL base model.

Table 20. Overview of model fit indicators - MNL models[10]

Model	**Initial log-likelihood**	**ASC**		**Costs**		**Time**	
		Final log-likelihood	**Rho square**	**Final log-likelihood**	**Rho square**	**Final log-likelihood**	**Rho square**
MNL Base	*-7607.93*	*-6312.438*	*0.170*				
Interaction effects with socio-demographics							
MNL Gender	-7595.454	-6290.069	0.172	-6302.465	0.170	-6303.602	0.170
MNL Age	-7607.93	-6180.694	0.188	-6267.907	0.176	-6225.102	0.182
MNL PT-Use	-7494.608	-6120.098	0.183	-6177.905	0.176	-6157.712	0.178
MNL Familiarity with shared modes	-7532.406	-6234.346	0.172	-6234.545	0.172		
MNL Previous use of shared modes	-7591.805	-6248.037	0.177	-6303.419	0.170		
MNL Income	-6120.05	-5118.073	0.164	-5130.571	0.162	-5126.98	0.162
MNL Level of education	-7249.218	-5967.374	0.177	-5990.51	0.174	-5989.859	0.174
Interaction effects with trip purpose							
MNL Purpose	-7607.93	-6306.59	0.171	-6309.039	0.171	-6305.789	0.171

According to the results, in terms of socio-demographics, it can be noticed that higher modal fit indicators are found when analysing interaction effects with ASC parameters, instead of time and cost parameters. This might suggest that socio-demographic characteristics affect to a greater extent the base perception of modes, rather than the sensitivity for time and cost. Regarding the effects of each socio-demographic characteristic, it is observed that including interaction effects with *age* and *frequency of use of public transport* seems to produce the highest improvement of model fit indicators. Accordingly, the respective results for the effects of said variables in the ASC parameters are discussed more in detail ahead in this section. However, some interesting findings from the other models are

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[10] Note that Initial log-likelihood is different in some models. This is caused by the necessary removal of observations in cases in which the studied characteristics were not specified by respondents.

worth mentioning. For instance, men seem to dislike metro and shared bicycle more than women, yet they seem to have a better perception towards shared mopeds. In addition, as it could have been expected, being familiar with shared modes affects positively the preference towards these modes. The latter is considered important, as it highlights the importance of encouraging the first experience of travellers using these modes. Regarding time sensitivity, it is noticed that in general older travellers and frequent public users tend to be less sensitive to time, in both main and egress legs. Hence, for the attraction of users improvements in this regard might not be as efficient in these groups as they might be in their counterparts. On the other hand, highly educated people, non-frequent PT users, and respondents with the highest income seem on average more sensitive to egress cost.

Concerning trip purpose, the inclusion of its effects does not cause great improvements in modal fit for any of the three estimated models. The most relevant insight that can be gained from these models is that respondents are more sensitive to walking time for commute trips as opposed to non-commute trips. The complete estimated results of MNL models with interaction effects (with socio-demographics and trip purpose) can be found in Appendix B.2.

Age effects

As mentioned before, the clearest age effects are observed when analysing them in relationship with the ASC parameters. Figure 29 presents how the different ASC parameters vary among age groups. In the figure, it can be noticed that the younger the group, the higher the base preference towards shared alternatives both as egress (*shared bicycle* and *shared moped*) and as main mode (*shared moped*). Hence, the results of this study suggest that young socio-demographic groups might be more likely to adopt shared modes as part of their mobility behaviour. The latter is not surprising, considering that previous studies such as (Van Kuijk et al., 2021) had already highlighted this tendency of younger people to be more likely to use shared modes than older people. Note that in general, the older the age group the further ASC values estimated are from ASC for car, which as explained before is fixed to zero. This might suggest that base preferences towards modes play a more relevant role for old groups than for younger groups.

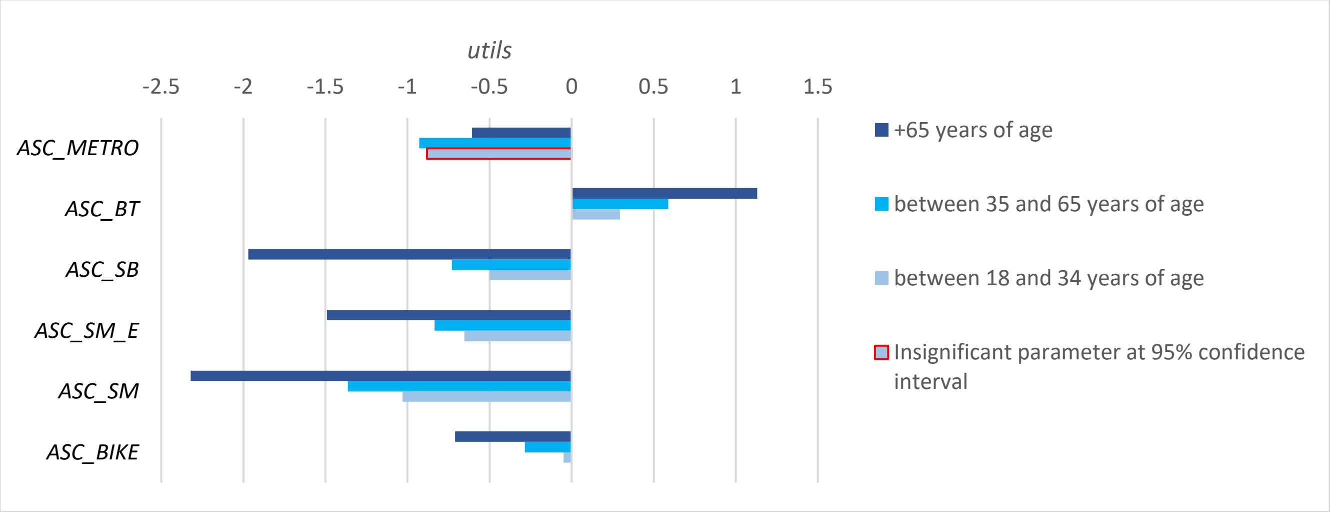


Figure 29. Age effects on ASC

Frequency of use of public transport

The variation of ASC parameters in function of the frequency of use of PT is presented in Figure 30. As expected more frequent travellers have a better perception towards metro regardless of cost and time attributes. The same holds for bus/tram as egress option, even though in this case it is important to note that the effect of travelling 1-4 times a week by PT is not statistically significant. In general, it seems that perception towards shared modes is positively affected by the frequency of use of PT. It is important to mention that these results go in line with the ones obtained in (Zhang & Zhang, 2018), which found a significant positive relationship between the frequency of PT use and the frequency of bike-sharing use.

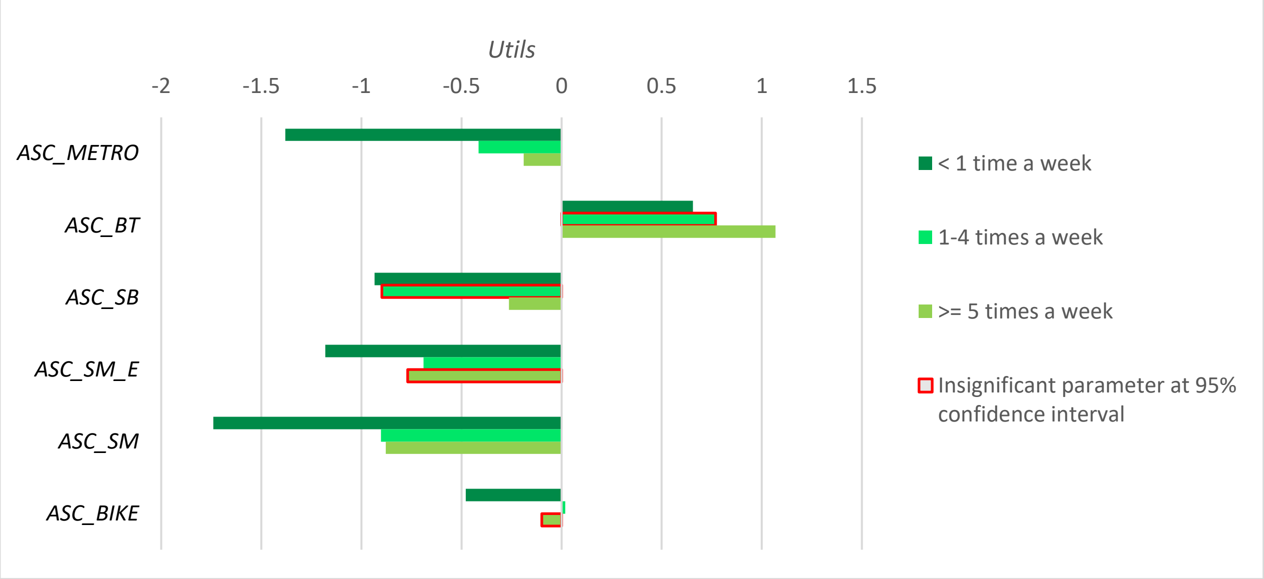


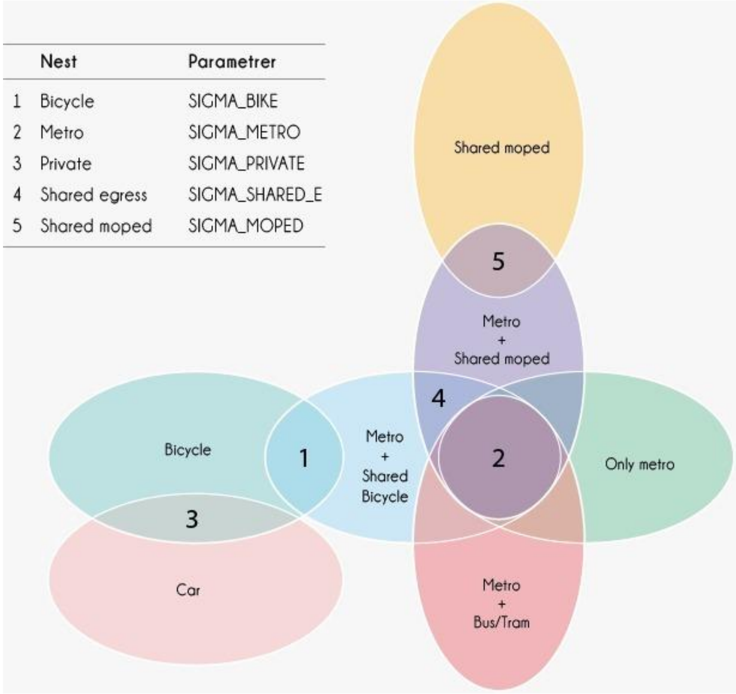
Figure 30. Frequency of use of Public transport effects in ASC

7.2 Mixed logit model (ML)

As explained in 4.2.2 the ML model allows capturing three types of effects that the MNL cannot: *Nesting of alternatives, parameter heterogeneity* and *Panel effects.* It is decided to divide this part of the modelling into three main parts. The first and second parts focus respectively on nesting of alternatives and parameter heterogeneity. It is important to mention that both effects are modelled with and without panel effects. Considering that results are considerably better in terms of model fit and statistical significance of parameters when including panel effects, and understanding that including them makes more behavioural sense, it is decided to base the analysis on the results of those models (See Appendixes C.2 and C.4 for a complete overview of results). Finally, the third part attempts to generate a better fitting model by using the outcomes of the first two parts. All the ML models without panel effects are estimated for one single random parameter for both nesting effects and parameter heterogeneity. In these cases simulation is not needed[11], so numerical integration is used as solving method because it considerably reduces computation times. When panel effects are included in the estimation, Monte-Carlo simulation is adopted as solving method.

7.2.1 Nesting effects

When observing the complete set of alternatives, some overlap among alternatives can be found. For instance, some of them have in common the presence of a certain mode, while others include modes that arguably share some characteristics (*e.g. privately owned*). Sets of overlapping alternatives are expected to have correlated preferences. To account for this, different expected nests are investigated using ML models. In terms of model definition, each nest is represented by the addition of an error term to the utility functions of the respective alternatives (equations 8-14). Figure 31 presents graphically the definition of nests, including also the random parameter associated with each of them.



	Nest	Parametrer
1	Bicycle	SIGMA_BIKE
2	Metro	SIGMA_METRO
3	Private	SIGMA_PRIVATE
4	Shared egress	SIGMA_SHARED_E
5	Shared moped	SIGMA_MOPED

Figure 31. Definition of nests

The additional error terms (*SIGMAS* in the table of the figure above) are assumed to be distributed across the population. However, it is uncertain which type of distribution represent each of them better. Following the approaches adopted in most studies consulted in which ML effects were estimated to capture nests, SIGMAS are assumed to be normally distributed.

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[11] Even though simulation is not necessary when a single random parameter is included, it can still be used if considered necessary

Initially, each nest is evaluated separately by estimating an ML model in which only its error term is included. After obtaining the results for the different nests separately, cross-nesting is evaluated. In this case, a single model is estimated in which all nests are included. The overview of model fit indicators is presented in Table 21. Note that generally speaking modal fit increases considerably compared to MNL models, especially in the cross-nesting model.

Table 21. Overview of model fit indicators – ML model to capture nesting effects

	Initial log-likelihood	Final log-likelihood	Rho square
Bicycle	-7607.93	-5587.28	0.266
Metro		-5588.17	0.265
Private		-5577.82	0.267
Shared egress		-6160.58	0.190
Shared moped		-6006.74	0.210
Cross-nesting		-4846.50	0.363

The correlation between alternatives within a nest is given by its *SIGMA* parameter. For all nests evaluated the obtained *SIGMA* are significant at a 99% confidence interval for single-nest as well as for cross-nesting models. In other words, the results of the ML models to capture nesting effects suggest that there are correlations among the error terms of the alternatives within all the different nests evaluated. Such correlations represent simultaneous 'like' or 'dislike' due to unobserved attributes within each of the nests. In Table 22 it is presented the magnitude of the parameters obtained for the cross-nesting model.

Table 22. Overview of nest parameters – Cross-nesting ML model

	Parameter	t-value
SIGMA_B	2.66	14.5
SIGMA_METRO	1.83	6.96
SIGMA_MOPED	2.22	10.3
SIGMA_PRIVATE	1.99	6.79
SIGMA_SHARED_E	1.43	4.64

At first glance, given the magnitude of its *SIGMA* value, one might think that alternatives within the *shared egress* nest are correlated to a lower extent than those within other nests. However, it is important to highlight that given the cross-nest composition some alternatives are affected by multiple parameters. For instance, the *metro + shared bicycle* and *metro + shared moped* alternatives are simultaneously part of two different nests. Hence, the correlation between these two alternatives is expected to be higher than what each of the *SIGMA* of the nests including them indicate.

7.2.2 Parameter heterogeneity

According to the base model formulation presented in subsection 7.1.1, two types of parameters are considered in this study: *tastes (BETAS)* and *alternative specific constants (ASC)*. Since both tastes and ASC are expected to vary across the population, the evaluation of taste heterogeneity is performed for both types of parameters. For the parameters representing tastes, seven different models are estimated: six with a single random parameter and one including all random parameters. For the *ASC* on the other hand, only one model including all parameters is estimated. The overview of modal fit indicators is presented in Table 23. Analogous to what is done in subsection 7.2.1 the random parameters are assumed to be normally distributed.

Table 23. Overview of model fit indicators – ML model to capture taste heterogeneity

Random parameter	Initial log-likelihood	Final log-likelihood	Rho square
B_EGRESS_COST	-7607.93	-5814.49	0.236
B_EGRESS_TIME		-5755.51	0.243
B_MAIN_COST		-5892.13	0.226
B_MAIN_TIME		-5813.25	0.236
B_WALK		-5892.91	0.225
B_METRO_WAIT		-5725.31	0.247
ALL BETAS		-5316.04	0.301
ALL ASC		-4618.73	0.393

Note that in general assuming parameters to be randomly distributed yields considerably better modal fit indicators than the ones obtained with the base MNL model (see Table 20), which might be an indicator of the relevance of variation of preferences across the population. The remaining of this sub-section discuss separately the effects of variation in *BETA* parameters (taste heterogeneity) and *ASC* parameters (mode preference heterogeneity).

Taste heterogeneity

In general, ML models to capture taste heterogeneity resulted in parameter estimates statistically significant at a 99% confidence interval. An interesting case occurs with the *B_METRO_WAIT* parameter, which is only significant in the two models in which its heterogeneity is taken into account. Contrastingly, in all other models, this parameter is consistently not significant, which is consistent with the results of the MNL models discussed in Section 7.1. The complete results of all models can be found in Appendix C.4. In this part of the results, only the taste distribution will be discussed, since the main objective in this part of the research is to understand how much tastes vary across the population, and what the effects of said variation are. The random distribution of each taste parameter is estimated twice. First in a model in which it is the only random parameter, and then in a combined model in which all random parameters are estimated simultaneously. Table 24 presents the mean values and the standard deviations for all parameters, estimated both separately and in a combined model. Note that in general, the size of taste parameters and sigma vary substantially when estimated all simultaneously compared to when they are estimated in separate models. Nonetheless, the size of tastes is hardly comparable from one model to another, since they explain different proportions of unobserved utilities, and as such the overall magnitude of parameters changes. Accordingly, as can be noticed in the complete results, not only do random taste parameters vary from model to model but also all other parameters. Notice also that for the combined model the sigma of the parameters *B_MAIN_TIME* and *B_METRO_WAIT* consigned in the table are zero, as they are found not to be statistically significant (t-values below 1). In terms of the implication for that specific model, the mean values would be assumed to apply to all the population.

Table 24. Random taste distribution – ML model to capture parameter heterogeneity

	Separate models		**Combined model**	
	meanβ	**σ**	**meanβ**	**σ**
B_EGRESS_COST	-1.65	1.37	-0.673	0.422
B_EGRESS_TIME	-0.236	0.239	-0.13	0.153
B_MAIN_COST	-0.29	0.442	-0.112	0.924
B_MAIN_TIME	-0.0409	0.155	-0.044	0
B_WALK	-0.17	0.196	-0.14	0.122
B_METRO_WAIT	-0.355	1.09	-0.068	0

Considering that tastes are assumed to be normally distributed, it is possible to represent graphically their respective estimates according to the models. Such graphical representation might help to visualize better what the models tell about the taste parameter's distribution. Accordingly, Figure 32 and Figure 33 present the distribution of parameters when estimated in separate and simultaneous models. Note that in Figure 33 no distribution is drawn for *B_MAIN_TIME* and *B_WAIT_METRO* parameters, as the results suggest that a normal distribution does not represent them significantly in this model formulation.

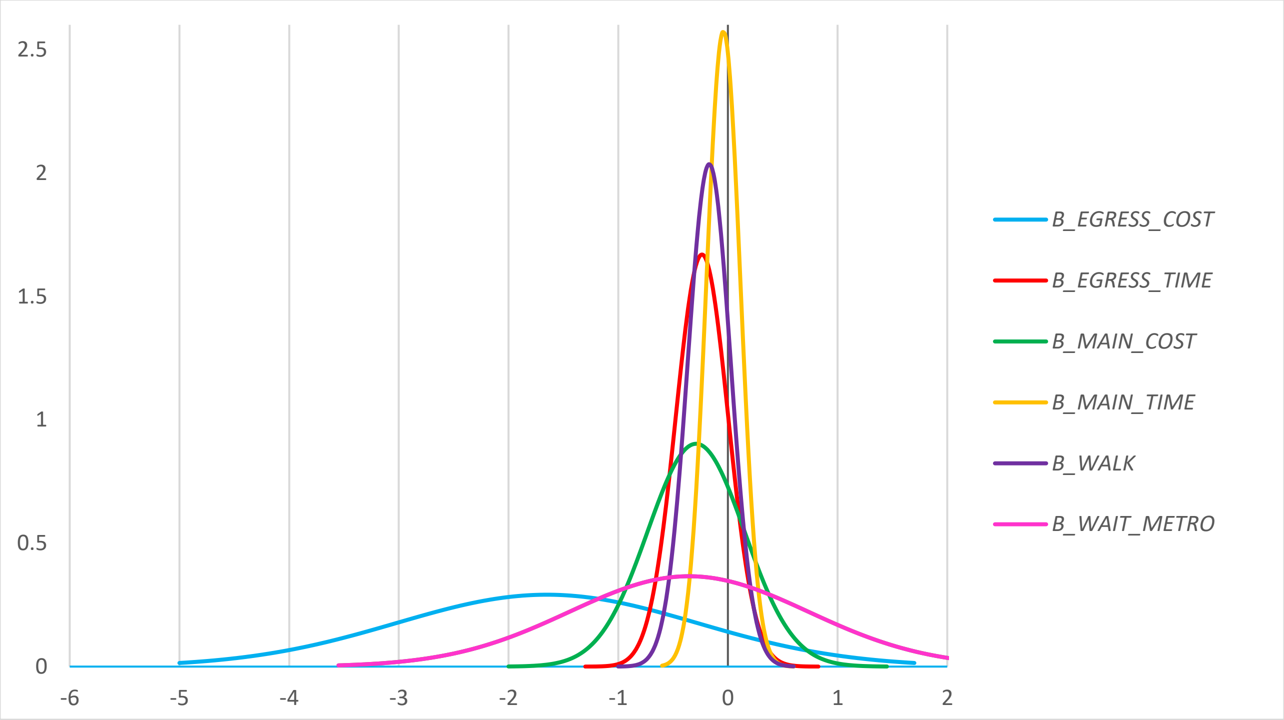

Figure 32. Taste parameters distribution – Separate models

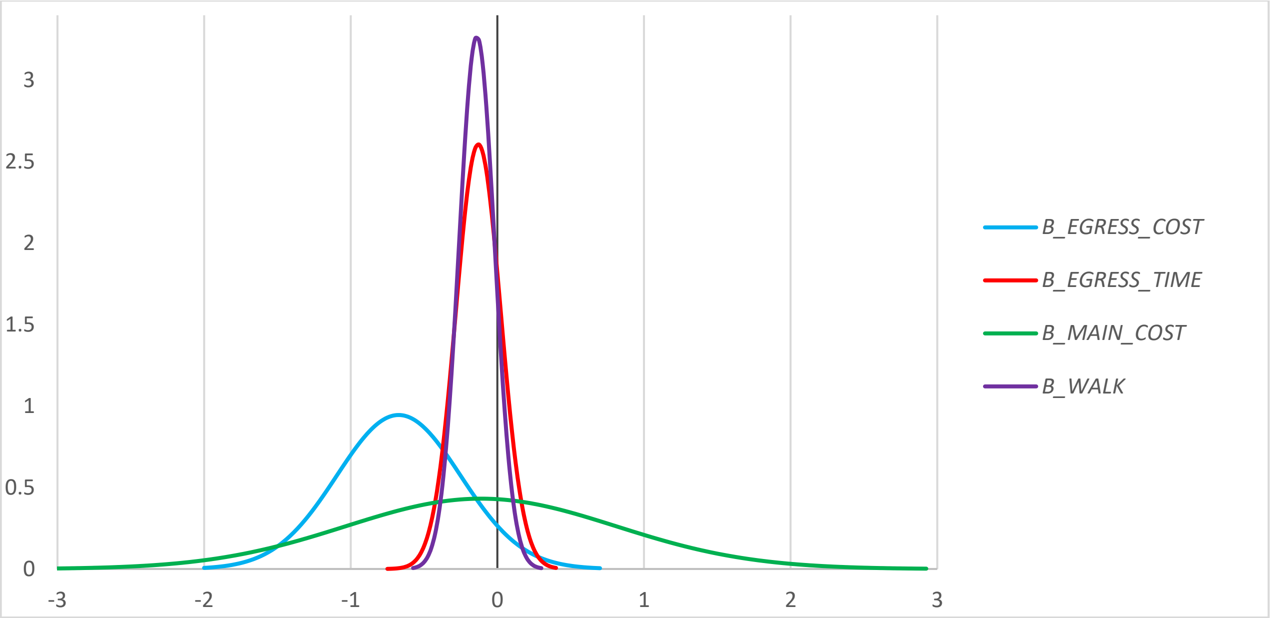

Figure 33. Taste parameters distribution – Simultaneous model

In general, the results in both models suggest that cost parameters are rather widely distributed across the population. In other words, while for some people the cost of the trip is a very relevant determinant of their choice of mode, for others its effect is more limited. Because of this, alternatives with similar cost characteristics are expected to be correlated, in a similar way to how alternatives with common characteristics (nesting) are. Something similar holds for waiting time, which according to Figure 32 has also a fairly wide distribution. Concerning other time parameters, it is interesting to see that in Figure 32 the distribution of the taste for travel time in the main mode is rather tight. This might help to understand why in the simultaneous model its variation is deemed insignificant. Accordingly, the results suggest that sensitivity for this characteristic of a trip does not seem to vary considerably amongst respondents. Note also that among time-related parameters, the one for egress time stands out as the one more broadly distributed. It is important to notice that according to the distributions displayed in the graphs, some might argue that a small percentage of the population is expected to have a positive taste towards cost and time. To try to tackle such an issue normal distributions were changed for lognormal distributions, yet they resulted in substantially lower modal fit indicators. Hence, for the subsequent model specifications with random parameters, the normal distribution was kept, taking into account however the limitations it might induce.

Mode preference heterogeneity

The approach to evaluating heterogeneity in ASC differs from the one followed for tastes as in this case all parameters are estimated only in a simultaneous model. Similarly to the other ML formulations, a normal distribution is assumed for the ASC parameters. Accordingly, for each mode, two parameters are estimated: the mean ASC, and its associated *SIGMA* associated with its variance. As explained in 7.1.1 the ASC for the car is fixed to zero, so it acts as a base alternative. Likewise, one of the *SIGMA* parameters also needs to be fixed to zero, more specifically the one associated with the smallest alternative specific variance. Since it is not possible to know which one it is, without estimating the model, a prior estimation of the model is performed in which all parameters are assumed to be distributed. From them, the *SIGMA* of the alternative exhibiting the smallest variance is fixed to zero, and then the model is re-estimated.

The complete results are presented in Appendix C.5, whereas the random parameters estimates are presented in Table 25. Note that the sigma associated with the parameter *ASC_SM* is fixed to zero, as the results in the preliminary model estimates suggest that its variation is the smallest. On the other hand, the mean *ASC_BT* according to the table is zero, even though in the complete results presented the value is different. The decision of assuming the value as zero is the fact that it is not found to be statistically significant. However, it is kept in the model as its standard deviation is both different to zero and statistically significant at a 99% confidence interval. Finally, see that consistent with the previous models, the mean *ASC_CAR* is fixed to zero.

Table 25. Random parameter estimates – ML to capture ASC heterogeneity

	mean	**σ**
ASC_BIKE	-0.561	3.02
ASC_BT	0	2.36
ASC_METRO	-1.07	2.37
ASC_SB	-1.89	2.09
ASC_SM	-1.7	0
ASC_SM_E	-2.19	2.36
ASC_CAR	0	2.45

Consistent with previous models, the mean ASC are all negative, which suggests an intrinsic preference towards the car that is not explained by the other parameters included in the model. However, since in this case the parameters are distributed, there is a certain probability of an individual having a preference towards one (or more) modes over that of the car. Figure 34 illustrates the distribution of the estimated parameters. Remember that *ASC_SM* is fixed to its mean value, so its value is shown with the dotted line. Note that the distributions of *ASC_CAR* and *ASC_BT* are very close to one another. However, it is important to take into account that this does not mean that the base preference of the modes is the same across the population, only that their distributions are very similar. According to the estimates, it is noticed that all parameters are rather widely distributed, which suggests high variation in the perception towards different modes across the population. As discussed in 7.1.2, some of this variation might be explained by the effects of socio-demographic and transport-related characteristics.

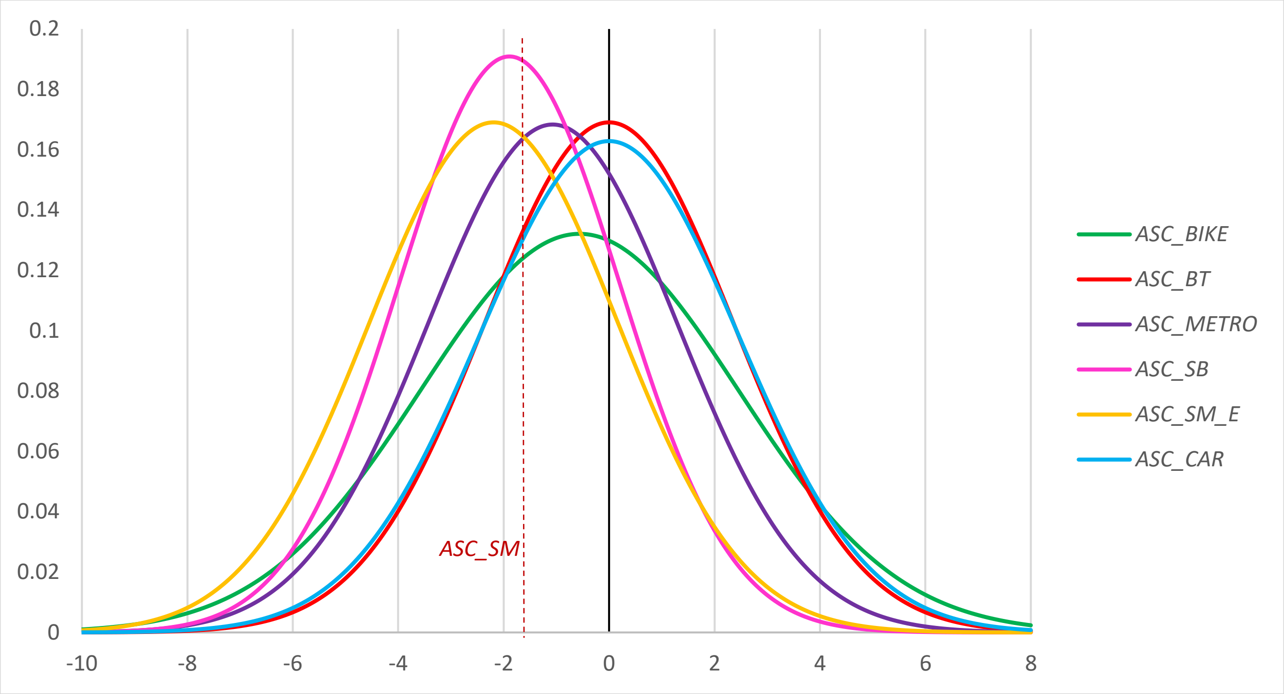

Figure 34. ASC parameters distribution

To sum up, parameter heterogeneity seems to be a relevant factor to consider in the context of this study. Even though it applies to a different extent to base modal preferences (ASC) and tastes towards time and cost (*BETAS*), the results suggest that their effects are substantial in both cases. Regarding tastes, it is important to highlight that except for travel time in the main mode, all other parameters associated with time and cost attributes are fairly distributed. Concerning ASC distribution on the other hand, variation in preference towards shared moped as individual mode seems to be lower than that of other parameters. Besides, it seems that on average there is no significant difference in base preferences of using metro+bus/tram and using only metro.

7.2.3 Combined ML model

Finally, a combined mixed logit model is estimated. In this combined model three types of effects are included: panel effects, nesting of alternatives and base mode preference heterogeneity. While previous models aimed at analysing different effects as interaction with socio-demographics, correlations between alternatives or how parameters vary across the population, this final ML model is mainly focused on checking whether model fit indicators can be further improved, and to test whether effects are still significant when modelled together. Table 26 presents the result of the model. As shown by its Rho-square indicator, the model does indeed improve previous model fit indicators considerably. Furthermore, it shows that when modelled simultaneously, some of both types of effects become insignificant, which might suggest that in this case is captured by some of the other effects included in the model. It is interesting to see, that consistent with the ML model to capture ASC heterogeneity presented in 7.2.2, ASC for bus/tram is not statistically significant, but its associated *SIGMA* is. It is important to mention that a model also including taste heterogeneity was estimated. However, many of the parameters of that model were mostly statistically insignificant, thus they are not included.

Table 26. Combined Mixed logit model results

			Rho-square	**0.399**
Name	**Value**	**Rob. SE**	**Rob. t-test**	**Rob. p-value**
ASC_BIKE	-0.785	0.137	-5.74	9.38E-09
ASC_BT	0.352	0.363	0.968	0.333
ASC_METRO	-1.3	0.293	-4.44	0.00000901
ASC_SB	-1.97	0.425	-4.64	0.00000349
ASC_SM	-2.34	0.253	-9.23	0
ASC_SM_E	-1.85	0.448	-4.13	0.0000368
B_EGRESS_COST	-0.709	0.113	-6.3	2.96E-10
B_EGRESS_TIME	-0.0749	0.0164	-4.58	0.00000471
B_MAIN_COST	-0.187	0.0185	-10.1	0
B_MAIN_TIME	-0.0717	0.00797	-9.01	0
B_WALK	-0.108	0.0138	-7.84	4.66E-15
Nest parameters				
SIGMA_B	0.215	0.137	1.58	0.115
SIGMA_METRO	1.88	0.218	8.61	0
SIGMA_PRIVATE	1.91	0.283	6.73	1.64E-11
SIGMA_BIKE	2.94	0.313	9.41	0
SIGMA_SHARED_E	1.26	0.345	3.64	0.000268
ASC heterogeneity parameters				
SIGMA_BT	2.32	0.18	12.9	0
SIGMA_CAR	2.09	0.226	9.24	0
SIGMA_SB	0.409	0.259	1.58	0.114
SIGMA_SM_E	-0.011	0.191	-0.0574	0.954

Legend: highlighted blue: significant at 99% confidence interval

7.2.4 Final remarks

Except for waiting time for metro, all other attributes included in the study are consistently significant across model formulations. According to this, it is noted that as expected they play relevant roles in mode choices under the context of this study. Note however that as discussed throughout this chapter, every factor affects choices differently. On the other hand, base preferences are found to be very relevant according to the model formulations. It highlights the importance of unobserved characteristics (within the model) on preference towards the different modes. Finally, as expected, some socio-demographic and transport-related characteristics stand out as they seem to have important effects on the attitudes of people towards shared modes.

It is important to highlight that when computing the value of time (VoT) based on parameters for the main leg of the trip, the values obtained are around 20 €/hour for most of the models, which is drastically different from other values found in the literature. For instance, van Kuijk et al. (2021) results suggest a VoT of around 7€/hour. Besides, the regional traffic and transport model of the Metropolitan Region of Rotterdam The Hague (MRDH) assumes a VoT of 8.21 €/hour and 10.13€/hour for non-work and work trips respectively. Note however that these values apply to car (van de Werken, 2018). The possible causes of these differences are further discussed in Chapter 8.

PART III:

Conclusion

8 Conclusions, discussion, and recommendations

Based on the objectives of this research, and considering the results presented in this document, this chapter concludes this project. It presents the conclusions that can be drawn from this research, the discussion of the results including the limitations of the study as well as how this research relate to existing literature, and recommendations for practice and future research.

8.1 Conclusions

Overall, this section discusses the different research questions and their respective answers according to what has been presented in this report. In addition, it includes the most relevant insights that have resulted from the different steps of the project, as well as their expected relevance. As presented in section 1, this research started by highlighting the need of public transport operators to make certain decisions about their reaction strategies to the emergence of shared modes. In concordance with that, the main research question formulated was:

From the perspective of public transport operators, how could integration with shared mobility affect mode choices within an urban environment, and how to positively influence this?

Answering directly the question is rather complex. It is noticed that before being able to do so, it is important to understand the underlying reasons behind user preferences towards shared modes along with how they relate to public transport in mode choice. Accordingly, a series of sub-questions were formulated to shape this research. To build up the answer to the main question logically, the following subsections discuss the sub-questions along with how the findings of this study relate to existing literature.

8.1.1 Public transport and shared modes: competition and complement

The literature reviewed before the problem definition suggested that shared modes and public transport relationship is characterised by both competitive and complementary relationships. As a result, the first sub-question aimed at ***identifying under which situations/conditions both types of relationships occur***. Complementary relationships are expected to occur mainly as a result of combined trip chains involving both types of transport modes. In said trip chains, the presence of shared modes might enhance the first/last mile legs of public transport trips, hence improving coverage and accessibility of Public transport. However, it is important to mention that as suggested by Meijering (2020), the extent to which combinations are expected highly depends on the modes in question. While metro and train are seen as potential modes to be combined with shared modes, for bus and tram this combination does not seem very likely. This research considered those expected relationships, and as such studied the potential use of shared bicycles and shared mopes as egress modes to the metro in particular. Figure 35 presents a recap of the results obtained in the survey in which respondents were asked to choose their preferred egress option in different contexts. As it can be observed, despite not being the overall preferred options, the 25% of choices towards shared modes suggest that they represent interesting alternatives for users, which supports the idea of complementarianism found in the literature. Note that in this study according to the levels varied in the choice sets included in the survey (see Table 9), one might argue that in all cases walking is a viable option, which could be related to the prevalence of choices towards this option. However, it is possible that in some cases egress distances are higher than what was included in this study. Hence, walking might not be a viable option, and as a result, one would expect the choice probabilities of local public transport and shared modes to increase.

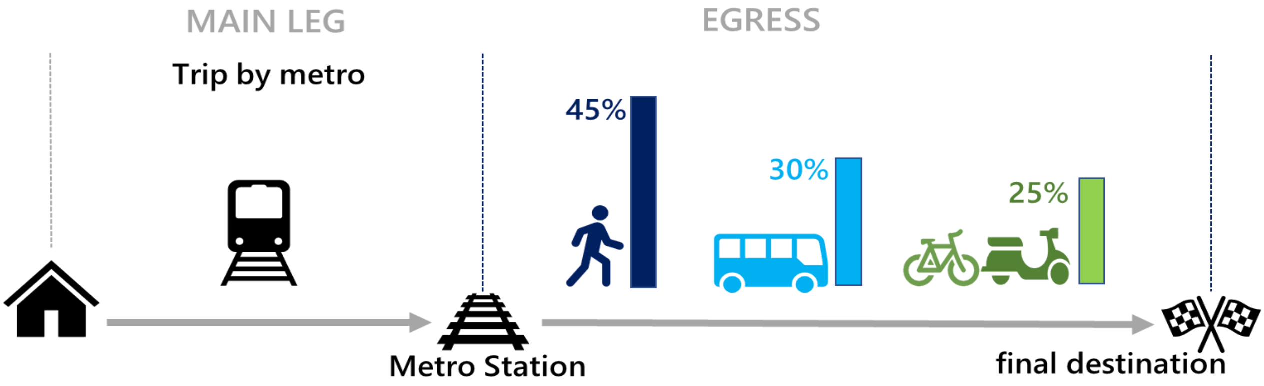

Figure 35. Overview of egress mode choices

On the other hand, competition between modes is mainly attributed to cases in which shared modes offer considerably better connections than public transit, especially in terms of travel time. For instance, Leth et al. (2017) and Machado et al. (2018) highlight that this tends to occur mainly in parts of the network where transit services are characterised by low speeds and large travel times, such as high-density areas and congested parts of the network. However, it is important to keep in mind that the extent to which relationships of competition/complement develop, highly depends on amongst other things, decisions by transport authorities and operators. For instance, if multimodality including transit and shared mobility is encouraged and facilitated, complementary relationships would be expected to occur at a higher extent that if they are not. Contrastingly, if no collaborations are put in place, shared modes and public transport would be expected to be seen as completely independent modalities, and as such more competition relationships could arguably be expected. Since a good integration between shared modes and public transit is assumed in this research, the extent to which competition between modes is evaluated is rather limited. This type of relationship is only included by evaluating shared moped as an individual alternative against multimodal metro trips and privately owned alternatives (*i.g. car and bicycle*). Even though the choice proportion of shared moped, in this case, is only 9%, the fact that some respondents choose it might be an indicator of the potential presence of competition between shared mopeds and public transport. However, since choice proportions in the case shared mopeds were not available are unknown, it cannot be concluded whether respondents that preferred this mode replaced private modes or transit, which could better explain if competition actually occurs.

In the following subsections, it is discussed how the trip characteristics (*i.e. time and* cost) affect choices for shared modes, which is the importance of the perception towards the different modes and (if applicable) which groups might/should be targeted in collaboration schemes according to their sociodemographic and travel behaviour characteristics.

8.1.2 Effects of personal characteristics

Different groups of people, depending on personal characteristics tend to vary in their preferences. Identifying some of those varying preferences among certain groups might be useful from a design and policy perspective. Accordingly, the second sub-question had the purpose of ***finding the effects of personal characteristics in preferences towards shared modes.***

In this research, personal characteristics are evaluated by introducing interaction effects with socio-demographics and transport-related aspects in the MNL model formulation. Regarding the former, according to the results age seems to be the most determinant factor, especially with regards to base preferences towards the different modes. Age showed to be a good indicator of preference towards the car, as ASC for all other modes increase in magnitude (remember that they are all negative) as the age increases. It holds for both shared bicycles and shared mopeds as egress modes, for which it seems that the younger the traveller, the more likely to use shared modes for last-mile. From a marketing perspective, it could be seen as an indicator of a potential group to target if collaborations schemes are to be designed. For time sensitivity the relation with age is quite the opposite, as age increases time parameters decrease. Gender on the other hand seems to have some effects especially in preference towards certain modes. Men appear to be more likely to choose shared moped as egress mode than women, while women show a more positive perception than men towards shared bicycle as egress. Income and level of education showed to have rather little effects in preference towards shared modes. Such gender effect found in this research somehow differs from previous studies in this area. For instance, no gender effect was not found by van Kuijk et al. (2021), and the effect found in Ma et al. (2020) is quite opposite to the one in this study, as the former suggests that men are more likely to use shared bicycles than women, and the results of this study point differently.

Concerning transport-related characteristics of respondents, it is noted that the frequency of use of public transport has an important influence on the perception of users towards the different modes. The preference for shared modes increases considerably as the frequency of public transport use increases. These results agree with (Zhang & Zhang, 2018), which found a positive correlation between frequencies of use of public transport and shared bicycles. Contrastingly, (van Kuijk et al., 2021) found that frequent public transport users are less likely to use shared modes in the last mile. Yet, the same study also highlights that having a public transport subscription affects positively the likelihood of using shared modes, which is expected to be a result of their desire to improve the experience in their public transport trips. Considering all these things, it would be reasonable to design schemes aimed at frequent public transport travellers, for whom it has been already observed a positive attitude towards shared modes.

Finally, as it will be further discussed in 8.1.3, ASC estimates for shared modes of those who have used shared modes previously are considerably higher than the ones for those who have not. Applied to the case of first/last mile trips, this could indicate that creating campaigns or pilots in public transport hubs that encourage users to try shared modes might help to improve the general perception of people towards these transport modes.

8.1.3 Mode related preferences

The quantity of aspects that affect mode choices is quite large, and thus mode choice models usually fail to capture them all in the form of attributes. Based on unobserved characteristics of each transport mode option (within the model), travellers tend to have base preferences towards the different alternatives. Accordingly, the third sub-question of this research was focused on understanding ***what the perception of travellers towards shared modes is in comparison with other alternatives, and to what extent it affects mode choices.*** To answer this question, base preferences for all alternatives were analysed along different stages of the project.

The results of the discrete choice models estimated suggest that characteristics proper of each mode different to time and cost have great importance in mode choice in the context of this study. This is reflected in the rather high alternative specific constants (ASC) estimated with all models, when they are compared to time and cost parameters. By definition, ASC is expected to capture the preference towards the different alternatives due to unobserved factors. Accordingly, they might reflect the importance of factors not included in the model such as comfort, ease of use, flexibility, among others. The results show that most negative perceptions are for the multimodal alternatives composed by metro and a shared mode. The latter suggests that if time and cost characteristics of transport alternatives are ignored, these multimodal options are the least appealing for users and thus would be expected to have the lowest shares. Nonetheless, time and cost are not easy to ignore in mode choice problems, being shared modes expected to benefit from it at least in terms of the former, considering that as argued by Leth et al. (2017) they can offer shorter travel times than other modes in many cases. Note that despite having the lowest ASC values, the choice probability for alternatives including shared modes still adds up to around 17% according to the MNL model (see Figure 28). It can be argued to indicate that there is room for shared modes in the mobility landscape, both as individual modes for the whole trip and as egress options for public transport trips. It is important to highlight that the perception towards shared modes as highlighted in the ASC values for the MNL model with interaction effects, improves considerably for those travellers who have previous experiences using them. In concordance with that, it seems that increasing awareness of people about shared modes, as well as removing barriers for them to use them in the first place, might help to increase their popularity.

It is interesting to see that even though mode preferences are strong according to the models, the portfolio of alternatives shows a rather high variation of modes from respondents. Hence, it could be argued that users might be willing to switch modes as long as they represent more convenient alternatives for them. The choice overview shows a high tendency towards public transport modes, even though in the sample around 75% only uses public transit modes twice a week or less. It is interesting to see that it seems that the metro becomes more appealing when the egress mode is bus/tram. It might indicate strong preferences towards public transport as a whole. In that sense, choices for bus/tram as egress option might suggest positive perception towards public transport, which are then also reflected in choice for metro. The opposite could be argued to happen with other modes, whose choice over bus/tram might in some cases reflect a general dislike towards transit, which then results in metro not being chosen. An example of this occurs with shared modes, which despite being chosen as egress mode once every four responses, when analysing the egress composition of the multimodal alternatives chosen, only account for 17% of the choices. The latter might suggest that even though shared modes can be interesting alternatives for egress legs of public transport, it does not necessarily translate into extra attractiveness of metro, at least when a big range of other alternatives are available. However, it is important to keep in mind that as already mentioned in 8.1.1 this is not always the case. Depending on the design of public transport networks, it is possible that public transport alternatives are limited or even inexistent in certain areas, or that transit services require long access/egress distances. In said cases, the popularity of shared modes can be expected to be higher, and probably as a result that of public transport too. Nonetheless, said effects are not considered in this study, and thus should be studied in further research.

In addition to the perception towards the different modes, the correlation of alternatives was evaluated using the Mixed logit. According to the nesting effects captured in it, the results of this study suggest that there is a high correlation between the preferences towards multimodal combinations *metro+shared bicycle* and *metro+shared moped*. This correlation is expected to reflect the importance of shared characteristics between modes, such as the flexibility of shared modes, the use of the metro for the main leg of a trip, the immediate availability of an egress mode, etc. In addition, shared bicycles seem to be highly correlated with private bicycles. It sounds reasonable considering that despite being accessed differently, in essence, both modes use the same type of vehicle. Considering the predominant positive perception towards bicycles in the Netherlands reflected in its cycling culture, this could be seen as a positive indicator of the potential of shared bicycles.

Finally, It is interesting to note that the results obtained in the study do not suggest a strong preference towards the car (16% of total choices), even though local statistics collected in Rotterdam highlight that in 2019 the shared of car trips was 42% (Gemeente Rotterdam, 2020). The characteristics of the trips included in the study might have played an important role in this aspect. However, in order to conclude anything concerning that, further study of characteristics of car trips is needed.

8.1.4 Effects of trip characteristics

The fourth and final sub-question aimed at studying ***how different trip characteristics affect choices towards shared modes in the context of this study.*** In this research, two trip characteristics were studied: time and cost, considering the effects of their respective components. After analysing the results of the multiple discrete choice models developed, different conclusions can be drawn. First, considering the magnitude of the parameters as well as the levels varied in the experiment, the results suggest that in the main leg travel time causes more disutility than travel cost. This suggests that travellers tend to be willing to pay for more expensive transport alternatives, as long as they take them faster to their destination. Nevertheless, it changes when the trip is done by a multimodal alternative with two distinct prices associated: the price of the main mode (metro), and the price of the egress alternative (e.g. bus/tram, shared vehicle, etc). In this case, the disutility caused by the extra cost due to the egress leg exceeds the one of travel time in the main leg and thus becomes of key importance for the choices towards these multimodal alternatives. The parameter for egress cost fluctuates around 5X the parameter for the main cost according to the estimated models. In other words, €0.50 of egress cost causes around the same disutility as €2.50 of main mode cost. This high cost sensitivity in the egress leg is expected to be a considerable demotivational factor against the adoption of multimodal alternatives including shared modes in the egress leg, especially if these modes have significant costs attached to them. Taking as an example the case of Rotterdam and RET, the way prices of shared modes are currently designed usually result in egress legs with a similar cost to that of the main leg (metro). If that is the case, and assuming that something similar holds in other cities in which collaborations are just under development or not intended at all, the price attached to shared modes might be holding back its growth as access/egress options. If transport authorities and operators are interested in boosting said growth, it seems reasonable to try to find pricing schemes that encourage the combination of modes. In this regard is also important to consider the variation of cost sensitivity across the population, which according to the ML model to capture taste heterogeneity (see sub-section 7.2.2) is fairly high.

Contrastingly to the case of cost parameters, the average taste parameter for egress time is consistently close to the one for the main time, hence indicating that there is no clear distinction in the way people weights the travel time of different trip stages. However, according to the results obtained for the evaluation of taste heterogeneity in 7.2.2, there is a difference in the way these parameters vary within the population. While most respondents seem to have a similar sensitivity to travel time in the main mode, the sensitivity to egress time seems to change more from one person to another. Furthermore, compared to travel time in main and egress modes, walking time does seem to be perceived more negatively, as its parameter is around twice the magnitude of the others, which can be expected considering the physical effort attached to it. Curiously, in average waiting time for metro does not seem to have a very significant effect as pointed by its lack of significance in most of the models; yet apparently, it is still considered by non-frequent PT users, as observed in the MNL model to evaluate the effects of frequency of PT use (see Appendix B.2), which might explain why it becomes significant when taste heterogeneity is considered. If these observations are combined with the ones regarding the sensitivity to the cost of alternatives, one might wonder about the feasibility of designing ways to offer complete trip chains as alternatives. In such a case, if a single price is given, then no distinction between trip legs would result in a single cost component, which one would expect to be weighted similar to the cost of the main mode. Even though the price would be similar (or the same) as the one when the traveller chooses main and egress modes separately, its perception might change.

8.1.5 Answer to the main research question

Considering what was discussed in the previous subsections of this chapter, the main research question can be answered now:

> Integration of public transport and shared modes can affect mode choice within the urban environment in multiple ways. On the one hand, shared modes seem to be appealing alternatives as egress modes for metro trips on a considerable amount of occasions. This can be attributed to a variety of factors, which following what has been already discussed in previous studies might include their flexibility, their ability to provide better accessibility to certain areas, or their rather high speeds, among others. Considering that satisfaction with public transport is affected by the whole door-to-door trip (Susilo & Cats, 2014), this might positively influence preference

towards transit services. Hence, by becoming attractive alternatives for last-mile connections, shared modes can be argued to serve indeed as a complement for metro, yet they would be expected to compete with other popular egress modes (activity side of the trip), such as the "second bike"[12], walking, or even bus/tram. In addition, shared mopeds proved to be an interesting alternative as an individual mode for long-distance trips, which in a way might support the idea of them being simultaneously complementary and competition to public transport, highlighted previously by Ricci (2015).

Considering the preferences and choice determinants exhibited for multimodal trips, to positively influence the effects of integration with shared mobility through collaborations, public transport operators should focus on four main things: *improving the door-to-door experience in terms of time, finding pricing schemes that limit the demotivation caused by egress cost, encouraging users to try shared modes for the first time,* and *targeting specific user groups.* To better explain the first two points, let's focus on Multimodal trips involving metro as the main mode, and a shared mode for the egress leg. Regarding improvements on the door-to-door experience in terms of time, as travellers seem to be similarly sensitive to time in the main leg (metro), and in the last-mile (shared mode), finding suitable combinations that improve total travel time might be beneficial, even if does so by reducing time in metro and increasing the one in shared modes. In other words, travellers seem to be willing to travel longer in their '*last-mile*', if it results in shorter overall travel times. Concerning cost, as highlighted in 8.1.4 the cost of shared modes as egress alternatives might be a strong disincentive against its use. If transport operators want to increase the share of multimodal trips involving transit and shared modes, pricing schemes should be thought carefully as not to link high costs to the egress leg in specific.

Besides, the results of this study suggest a clear positive attitude towards shared modes of those who have used them before. Accordingly, it seems reasonable to think that encouraging a first experience with shared modes, can positively influence the overall perception of users towards these modes. Finally, young people and frequent public transport users showed considerably better perceptions about shared modes than their counterparts. Accordingly, it might be interesting to design strategies to specifically target these groups.

It is important to remember that in the problem definition (see Section 1.3) it was explicitly mentioned the need to analyse the effects of shared modes in the overarching choice of using or not public transport. According to the results and context of this research, said effects did not stand out in the different mode choice models developed and analysed. In addition to being attractive egress alternatives, there are no other findings in the results that suggest that the availability of shared modes for the last part of the trip makes the metro a more appealing alternative. Nonetheless, based on this study it cannot be concluded that said effect does not exist, as some highlighted potential benefits of the integration between shared modes and transit are not studied in this research.

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[12] On average the Dutch own 1.3 bicycles per capita (BicycleDutch, 2018), which means that a considerable amount of the population has more than one bicycle.

8.2 Discussion

Following the presentation of the main conclusions of the study as well as how they compare to existing literature, this section presents the discussion of this research, in terms of the methodology adopted, the decisions/assumptions made during the project, and the conditions under which this research was carried out.

8.2.1 Assumed context

According to the literature reviewed in the early stages of the project, there are different factors related to the integration of shared modes with public transport that are expected to have an important impact on the effects of the integration. Among those factors, the availability of shared modes in (or close to) public transit stations, high docking capacities at said locations, and uniform ticketing systems stand out as some of the most important (Böcker et al., 2020; Ma et al., 2020; Oeschger et al., 2020; Shaheen, 2016). Even though meeting all those conditions has proven to be a great challenge, the collaborations in place between stakeholders suggest that the availability of modes in PT stations and trip planning stages of trips might not be a problem in the near future. Hence, this study assumes that these conditions have been satisfied. When analysing the results, it is important to bear in mind that they are based on a hypothetical scenario, which even though is considered likely to occur, does not reflect current real conditions. Besides, by assuming this scenario and making it part of the context of the study, this study ignores the effects that failing to achieve said levels of collaboration might have on people's choices, and hence in the way integration between public transport and shared modes might affect mode choice. For instance, uncertainty regarding the availability of shared modes close to PT stations would be expected to discourage travellers to considered shared modes for their egress trips (Böcker et al., 2020; Oeschger et al., 2020), hence causing preference towards these modes to be worse-off. However, this study does not capture those effects.

In addition, it is important to remember that parameter and choice probabilities were computed assuming scenarios in which all modes are feasible alternatives, yet in reality, this is not always the case. As a result, this study in a way ignores cases in which shared modes might be the only (or at least the clearly most convenient alternative) for last-mile trips. For instance, those cases in which the final destination is rather far away from the metro station, and other public transport connections do not offer the desired connectivity. Accordingly, one of the main potentials of shared modes according to the literature reviewed is not included in this research: their ability to extend catchment area of PT services, by making it possible to reach destinations not easily accessible with other modes. Hence, as stated in this research does not allow to conclude against the possibility of shared modes representing an addition in terms of attractiveness for public transport modes, such as metro for example.

Even though both shared bicycles and shared mopeds were included as possible egress modes, only the latter was considered as a relevant alternative to cover the whole trip. Shared bicycle was not researched as an individual mode for the whole trip chain, while in reality, it might be an option. The decision of not including it, in this case, is related to the nature of the trips assumed: activity-based trips starting at home. Given the predominant cycling culture of the Netherlands, and considering the high levels of bicycle ownership: around 84% of the population owned at least one bicycle by 2018

(CyclingDutch, 2018); it is considered very likely that users would have the option of using their bicycles. Accordingly, when designing the study it did not seem very relevant to add the shared bicycle as an option, as respondents would have been expected to prefer their own. Moreover, adding them would have added complexity to the stated choice experiment, both in terms of design and burden for respondents. However, as a result of this choice, the probability of shared bicycles being used in the expected few cases in which people do not have a bicycle available at home or prefer not to use it are ignored in the study. Furthermore, this research is based on trips from home to an activity location. How integration could influence mode choice in the opposite direction is not studied. In this case, different mode availabilities can be expected. For instance, private bicycles might be available as egress mode from the transit station.

Finally, when defining the choice context for the stated choice experiment, some things that in reality are variable as assumed as constant, and thus their effects are ignored. For instance, the weather in some cases might be a reason not to use certain modes, yet said effects are not captured in this research. Something similar holds for the assumption of travellers not carrying large/heavy luggage. If they were, it does not seem very likely that they can replace the bus or the tram with a shared bicycle for instance.

8.2.2 Methodology

The methodology adopted in the project relies heavily upon stated preference data. However, the choices made by respondents in the respective SC experiment, do not necessarily represent the choices that respondents would make in reality. It is important to bear in mind that in real-life situations travellers might weigh factors differently than the way they showed in the experiment. For instance, people are understood to overestimate their economic valuation of a good under stated preference settings (Murphy et al., 2005). Applied to the context of this study, this might be argued to be a possible explanatory factor of the rather high values of time found in this study. Furthermore, this might also suggest that the range of prices varied in some of the scenarios is not big enough to become a decisive factor. Accordingly, studying the effects of price more in-depth could be important. On the other hand, in the MNL model with interaction effects, all socio-demographic and transport-related characteristics were modelled separately. However, it is possible that some of them are correlated and that these correlations might have affected the results.

An important factor in mode choice related to public transport is the effect of transfers in choices made by people. Depending on them users might be willing to use certain modes for their egress trips to a higher or lesser extent. For example, Van Kuijk et al. (2021) highlights that the likelihood of using shared modes as egress options decreases as transfers are included within the transit leg. Besides, people tend to be willing to cycle longer to avoid public transport transfers (van Mil et al., 2020). According to the choice context assumed, this study does not include said factors, which might in reality represent an important factor to consider.

8.2.3 Limitations of the sample

As mentioned in sub-section 6.1.1 the population from 18 to 25 years of age as well as the one over 75 are miss represented in the sample. Considering that age proved to be a very relevant determinant of preferences towards certain modes, this limitation is expected to have a considerable effect on the results obtained with this study. Remember that for instance, youngest age groups exhibited a more positive attitude towards shared modes, which might be underrepresented in the sample. Besides, the results suggest that gender also has an influence especially in mode preference, being men more open towards shared moped and car, whereas women showed to be more likely to choose both metro alternatives and shared bicycle for the egress. The sample however has an over-representation of women, which might have induced some biased in the results. Remember, that metro stood out as the most repeatedly chosen alternative.

The responses of the survey were collected using a commercial panel, which could be argued to be biased in certain aspects. For example, since respondents are attracted via digital platforms, there could be some bias in favour of frequent users of digital means. Furthermore, the commercial panel mainly target Dutch people, as suggested by the requirement of publishing the survey in Dutch, yet Rotterdam like other major cities in the Netherlands has important migration of people from other parts of the world, which are very likely not represented in the sample.

8.2.4 Other limitations

In addition to the previously discussed limitations, others need to be mentioned. For instance, the cycling culture of the Netherlands is expected to play an important part in influencing preferences. Thus, transferring results to other countries with different infrastructure and behavioural characteristics need to be done carefully. Furthermore, the characteristics proper of the public transport system are key determinants of the way shared modes relate to its services. The results obtained in this study are expected to be biased by the perception of the public transport network of Rotterdam, yet this varies between cities, even in the same country.

It is also important to mention the possible effects of COVID-19. Travel behaviour has changed greatly as a result of the pandemic, and the results of the study can be affected by changes in perception towards modes caused by it. Furthermore, it is still unknown to what extent the pandemic will affect people's perception in the long term.

8.3 Recommendations

Finally, this section presents the most important recommendations derived from this research. It divides them into two categories. First, recommendations for practice, with a special focus on public transport operators. Second, recommendations for academia in which potential future research related to this topic is highlighted.

8.3.1 For practice

Different collaborations are now in place to improve integration between transport alternatives, including public transport, shared modes, ridesharing services, etc. In this context, and from the point of view of public transport operators, this study might have interesting insights worth being considered. Firstly, the overview of results as well as the portfolios of alternatives show that under conditions of integration with public transport, shared modes are seen as a viable egress solution by a considerable fraction of travellers, and hence it should be treated as such. By being used for egress legs, shared modes can improve the overall perception of users towards public transport. Furthermore, even though the effects of improvements in the catchment area of transit networks are not explicitly considered in this research, the fact that users might consider shared modes for their last mile might indicate that this effect is likely to occur. Accordingly, it is advised for public transport operators to identify potential areas in which the accessibility they provide is insufficient, and to explore with shared modes to try to partially tackle this issue.

Secondly, the finding of travel time being weighted nearly in a uniform way for both main and egress leg might be an important aspect to consider from a strategic perspective. Contrastingly, egress cost seems to be heavily perceived by travellers. The disutility it causes is considerably higher than the one caused by the cost in the main leg. These results might be argued to suggest that longer egress legs are not necessarily a bad thing, as long as they help to reduce total travel time, and they do not induce much extra cost for travellers. Considering these points, it is advised to conceive integration between public transport and shared modes in such a way that planning of public transport services considers egress leg as an integral part of the trip, and not only as of the 'last-mile' that needs to be solved. To do that, it is important to find the right strategies in terms of collaboration with shared mobility providers, or even in terms of their own offer. While multiple transport operators offer their own shared services (take *HTM-fiets* or *OV-fiets* as examples), some others collaborate by combining their offers into shared platforms. Which scheme of integration is the most appropriate is not studied in this research. However, from the author's perspective, it is argued that by offering their own shared mobility services, public transport operators might have more freedom that could allow them to design better their multimodal offers. As a result, they might maximize the benefits for them of the integration between transit and shared mobility.

An interesting finding of the study, though expected, was the correlation in preferences between private and shared bicycles, captured by the mixed logit model. Given the predominant cycling culture of the Netherlands, said correlation might indicate the potential of shared bicycles. Although in many cases people have their bicycles available, there are numerous cases in which they might not. It would be recommended to target those cases when considering shared bicycles as egress enablers. As it is already known that in general Dutch citizens do feel comfortable cycling, shared bicycles might appear as an interesting alternative as long as they do not generate much extra cost.

Considering the importance of personal and transport-related characteristics highlighted in 8.1.2, it is also recommended the targeting of specific groups in the design of integrated offers. On the one hand, existing positive preferences should be exploited. Hence, by aiming offers towards young people and frequent public transport users. On the other hand, some of those with negative perceptions towards these combinations can be nudged by encouraging them to try shared modes for the first time. Remember that the results of this study suggest that those who have used shared modes previously have on average better perception towards these modes, and thus are expected to use them more often.

8.3.2 Future research

As discussed in this document, the role of shared modes within the mobility of cities is a relevant topic nowadays. Studying it more in-depth might help to understand better how they relate with other modes, and especially how to react to their emergence to achieve the ultimate goal of more sustainable mobility. As extensively discussed in this chapter, a big gap in the literature that is still to be studied is that of understanding to what extent can shared modes help to enhance coverage of public transport, and how that can affect mode choice. Accordingly, it is recommended to research the effects of mode choice under integrated public transport and shared mobility services, under a context in which public transport would not be a feasible option without the presence of shared modes.

On the other hand, this study provides different model formulations that can be used as tools to model mode choice related to public transport and shared modes. The outcomes of this study can be further exploited if they are applied to explore how different reaction strategies from public transport and government policies affect the use of the different modes. For instance, changes in public transit networks in terms of line density, stop spacing, frequency and coverage can be analysed. In addition, it would be interesting to understand to what extent each assumed characteristic of the integration affects the level of complement or competition between public transport and shared modes. For example, it seems relevant to study the real effect of availability of shared modes in transit stations, which amongst other things might help to grasp thresholds regarding for example quantity of vehicles that assure travellers that they will encounter available vehicles at their arrival at the station. Additionally, it might also help to realize which business models and collaboration strategies are more convenient for policymakers and transport operators.

This research studied explicitly shared modes preferences in the context of egress modes of home-activity trips. Preferences in other first/last mile situations would be expected to differ to a certain extent. Besides, in different cases, different modes might be available. Accordingly, further research is recommended in which this can be studied. Finally, there are several different shared modes not included in this research, which might be interesting to study as well, such as e-bikes, e-scooters (steps) or shared cars. Furthermore, this study is focused on dock-less shared systems, towards which preferences associated are expected to be different to those of station-based shared modes. Accordingly, future research can compare the effects of sharing schemes on the preferences of users under integrated systems.

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APPENDIX

A. Stated Choice Experiment

A.1 Syntax

Egress mode choice

```
? D-efficient design-egress
? D-efficient design- egress
? Middle values forced to appear 3 times -> Otherwise it tends to the extreme values
? With logical operations to make tasks more realisticDesign
;alts = BT, Bike, Moped, Walk
;rows = 9
;eff = (mnl,d)
;alg=mfederov
;require:
Walk.total_walk > Bike.in_vehicle_b,
Bike.in_vehicle_b >= Moped.in_vehicle_m,
Bike.Cost_bike < Moped.Cost_moped
;model:
U(BT) = c_BT[0.1455] + b1[-0.112]*wait[2,5,8](2-4,3,2-4) + b20[-0.07]*in_vehicle_bt[5,7,9](2-4,3,2-4) + b3[-
0.168]*walk_dest[1,3,5](2-4,3,2-4) + b4[-0.207]*Cost_pt[1.2,1.7,2.2](2-4,3,2-4) /
U(Bike) = c_Bike[-0.804] + b21[-0.051]*in_vehicle_b[7,10,13](2-4,3,2-4) + b5[-0.432]*Cost_bike[1.2,1.7,2.2](2-
4,3,2-4) /
U(Moped) = c_Moped[-1.802] + b22[-0.072]*in_vehicle_m[5,7,9](2-4,3,2-4) + b6[-
0.798]*Cost_moped[1.7,2.2,2.7](2-4,3,2-4) /
U(Walk) = b7[-0.101] *total_walk[12,16,20](2-4,3,2-4)
$
```

Complete trip mode choice

```
? D-efficient - Complete trip
? Middle values forced to appear 3 times -> Otherwise it tends to the extreme values
? With logical operations to make tasks more realistic
Design
;alts = Metro, Car, Bike, Moped
;rows = 9
;eff = (mnl,d)
;alg=mfederov
;require:
Moped.moped_time < Bike.bike_time
;model:
```

U(Metro) = c_Metro[u, -4.56, -1.65] + m0[-0.0738]*m_wait[1,3,5](2-4,3,2-4) + m1[-0.06]*m_time[10, 15, 20](2-4,3,2-4) + m2[-0.207]*m_cost[1.8, 2.4, 3](2-4,3,2-4) /
U(Car) = b8[-0.079]*drive_time[20, 25, 30](2-4,3,2-4) + b9[-0.098]*travel_cost[2, 4, 6](2-4,3,2-4) + b10[-0.178]*Parking_cost[0, 5, 10](2-4,3,2-4) + b3[-0.101]*walk_dest[1, 3, 5](2-4,3,2-4)/
U(Bike) = c_bike[-0.741] + b23[-0.076]*bike_time[20, 25, 30](2-4,3,2-4) /
U(Moped) = c_moped[-2.69] + b24[-0.06]*moped_time[15, 20, 25](2-4,3,2-4) + b11[-0.023]*search_time[1,3,5](2-4,3,2-4) + b6[-0.798]*Cost_moped2[4, 5, 6](2-4,3,2-4)
$

A.2 Experimental design

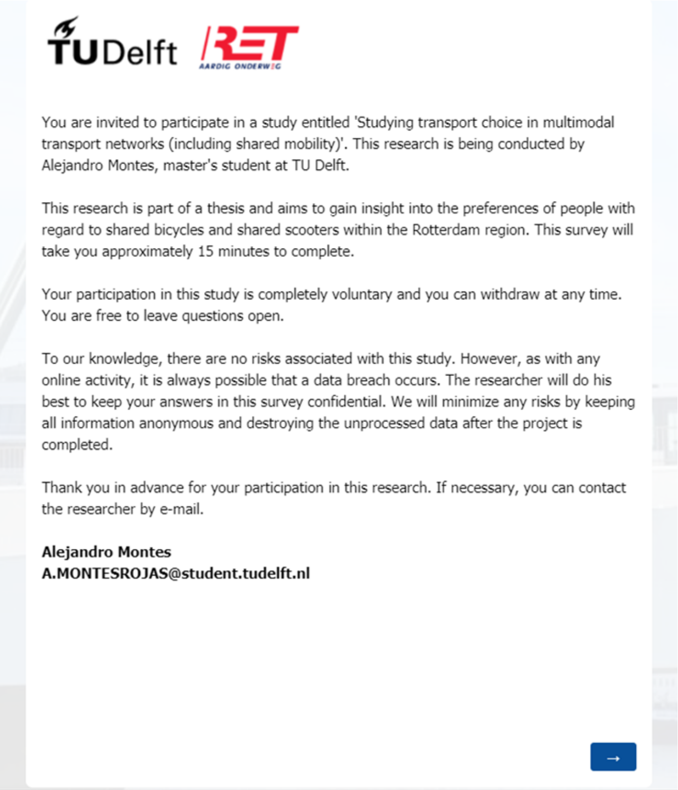
Experimental design – Egress mode choice

Choice situation	Bus/Tram				Shared bicycle		Shared moped		Walking
	Waiting time	In-vehicle time	Walking time	Cost	In-vehicle time	Cost	In-vehicle time	Cost	Walking time
1	5	9	5	1.2	7	2.2	7	2.7	20
2	5	9	1	1.7	13	2.2	5	2.7	20
3	5	7	5	2.2	10	1.2	9	1.7	20
4	2	5	3	1.7	13	2.2	9	2.7	16
5	8	5	3	2.2	13	1.2	5	1.7	16
6	8	5	1	1.2	10	1.7	7	2.2	16
7	2	7	1	2.2	7	1.2	7	1.7	12
8	2	7	5	1.2	10	1.7	9	2.2	12
9	8	9	3	1.7	7	1.7	5	2.2	12

Experimental design – Complete trip mode choice

Choice situation	Metro			Bike	Shared moped			Car			
	Waiting time	In-vehicle time	Cost	In-vehicle time	In-vehicle time	Search time	Cost	In-vehicle time	Walking time	Cost	Parking cost
1	5	10	2.4	25	20	3	5	20	3	4	0
2	1	10	2.4	25	20	3	6	20	3	4	10
3	3	20	2.4	25	20	1	5	25	1	2	10
4	1	10	3	30	15	1	6	30	3	4	5
5	3	15	3	30	25	3	4	30	1	6	0
6	5	10	1.8	30	25	5	4	25	5	2	5
7	1	15	1.8	30	25	5	5	20	5	6	10
8	3	20	1.8	20	15	1	4	25	5	2	0
9	5	15	3	20	15	5	4	30	5	6	5

A.3 Survey



You are invited to participate in a study entitled 'Studying transport choice in multimodal transport networks (including shared mobility)'. This research is being conducted by Alejandro Montes, master's student at TU Delft.

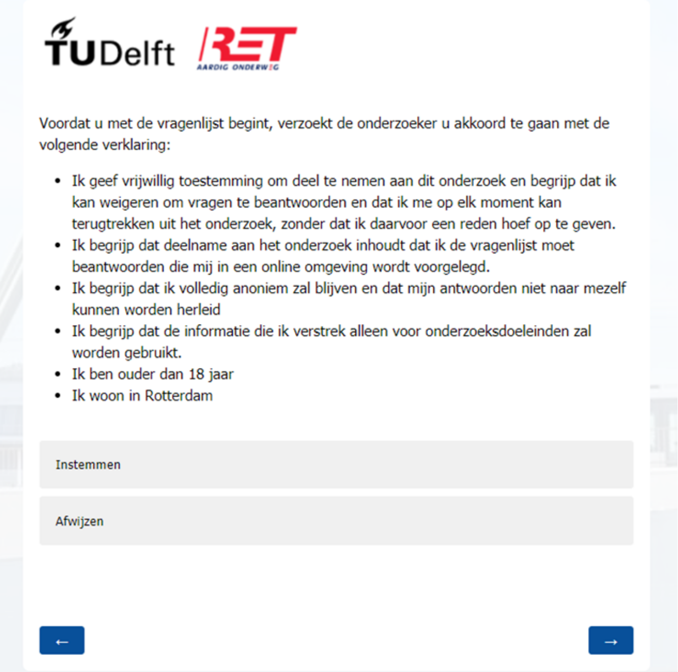
This research is part of a thesis and aims to gain insight into the preferences of people with regard to shared bicycles and shared scooters within the Rotterdam region. This survey will take you approximately 15 minutes to complete.

Your participation in this study is completely voluntary and you can withdraw at any time. You are free to leave questions open.

To our knowledge, there are no risks associated with this study. However, as with any online activity, it is always possible that a data breach occurs. The researcher will do his best to keep your answers in this survey confidential. We will minimize any risks by keeping all information anonymous and destroying the unprocessed data after the project is completed.

Thank you in advance for your participation in this research. If necessary, you can contact the researcher by e-mail.

Alejandro Montes
A.MONTESROJAS@student.tudelft.nl



Voordat u met de vragenlijst begint, verzoekt de onderzoeker u akkoord te gaan met de volgende verklaring:

- Ik geef vrijwillig toestemming om deel te nemen aan dit onderzoek en begrijp dat ik kan weigeren om vragen te beantwoorden en dat ik me op elk moment kan terugtrekken uit het onderzoek, zonder dat ik daarvoor een reden hoef op te geven.
- Ik begrijp dat deelname aan het onderzoek inhoudt dat ik de vragenlijst moet beantwoorden die mij in een online omgeving wordt voorgelegd.
- Ik begrijp dat ik volledig anoniem zal blijven en dat mijn antwoorden niet naar mezelf kunnen worden herleid
- Ik begrijp dat de informatie die ik verstrek alleen voor onderzoeksdoeleinden zal worden gebruikt.
- Ik ben ouder dan 18 jaar
- Ik woon in Rotterdam

Welkom!

In dit onderdeel wordt u een aantal vragen gesteld die gebruikt zullen worden om inzicht te krijgen in uw voorkeuren ten aanzien van deelfietsen en gedeelde scooters en uw beweegredenen om er al dan niet mee te reizen. Deelfietsen en scooters zijn voertuigen tot welke u toegang kunt verkrijgen met behulp van een speciale app op uw smartphone. Voor dit onderzoek gaan we ervan uit dat deze voertuigen bijna overal in de stad kunnen worden gevonden en achtergelaten. Voorbeelden van aanbieders van deze gedeelde voertuigen in Rotterdam zijn:

- **Gedeelde fietsen:** Donkey Republic, Mobike
- **Gedeelde scooters:** Felyx, Check, GoSharing

Het onderzoek is opgedeeld in 3 delen:

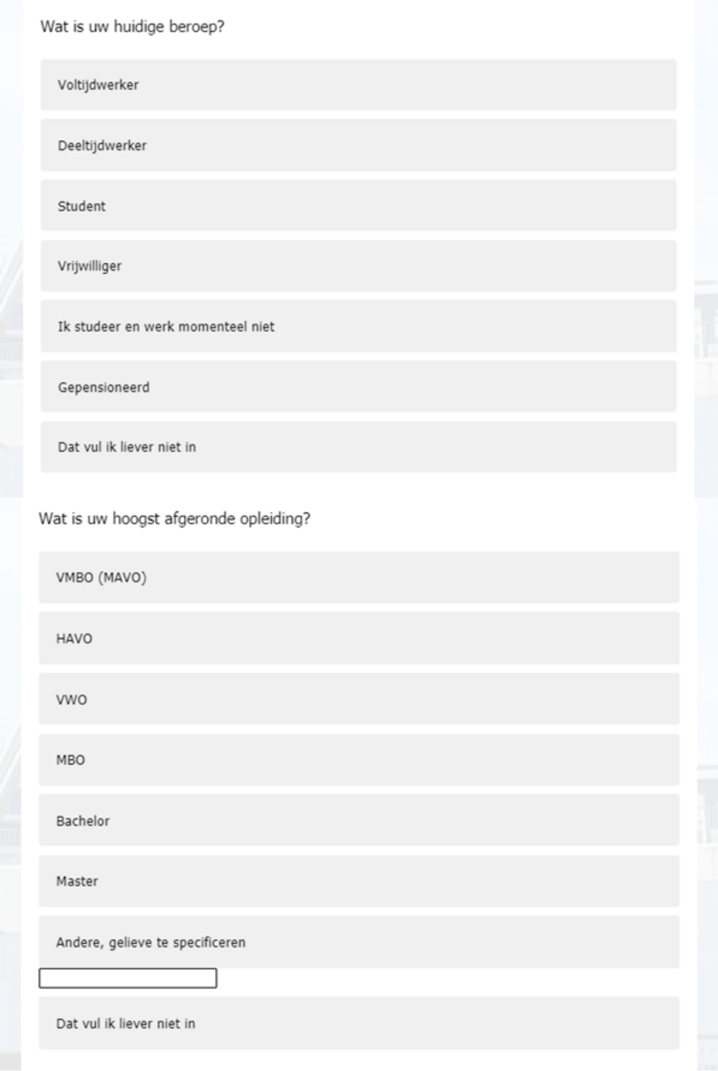
1. In het eerste deel wordt u gevraagd om algemene informatie te geven over uw sociodemografische achtergrond.
2. In het tweede deel worden u enkele vragen gesteld over uw huidige reisgedrag en welke voertuigen u in het algemeen ter beschikking staan.
3. In het derde en belangrijkste deel worden u negen hypothetische scenario's voorgelegd, waarin u wordt gevraagd te kiezen met welk vervoermiddel u het liefst zou reizen onder een aantal wisselende omstandigheden.

DEEL 1: SOCIODEMOGRAFISCHE INFORMATIE

In dit deel wordt u een aantal vragen gesteld over uw persoonlijke achtergrond. Het staat u vrij de vragen waar u zich niet prettig bij voelt, niet te beantwoorden. Gelieve in dat geval de laatste optie "Dat vul ik liever niet in" aan te kruisen.

Kunt u uw geslacht specificeren?

Kunt u aangeven in welke leeftijdscategorie u valt?

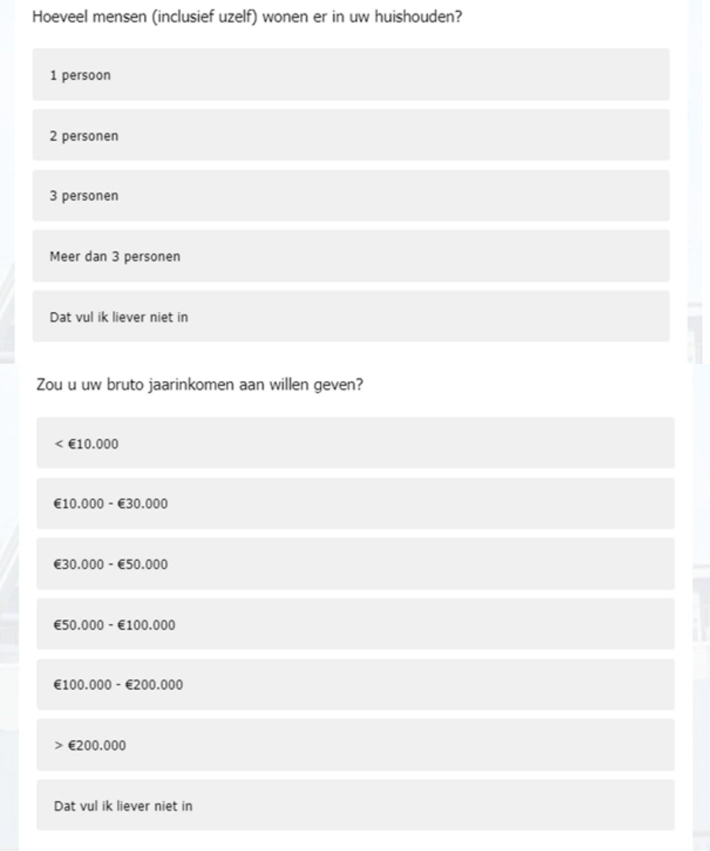


Wat is uw huidige beroep?

- Voltijdwerker
- Deeltijdwerker
- Student
- Vrijwilliger
- Ik studeer en werk momenteel niet
- Gepensioneerd
- Dat vul ik liever niet in

Wat is uw hoogst afgeronde opleiding?

- VMBO (MAVO)
- HAVO
- VWO
- MBO
- Bachelor
- Master
- Andere, gelieve te specificeren
- Dat vul ik liever niet in

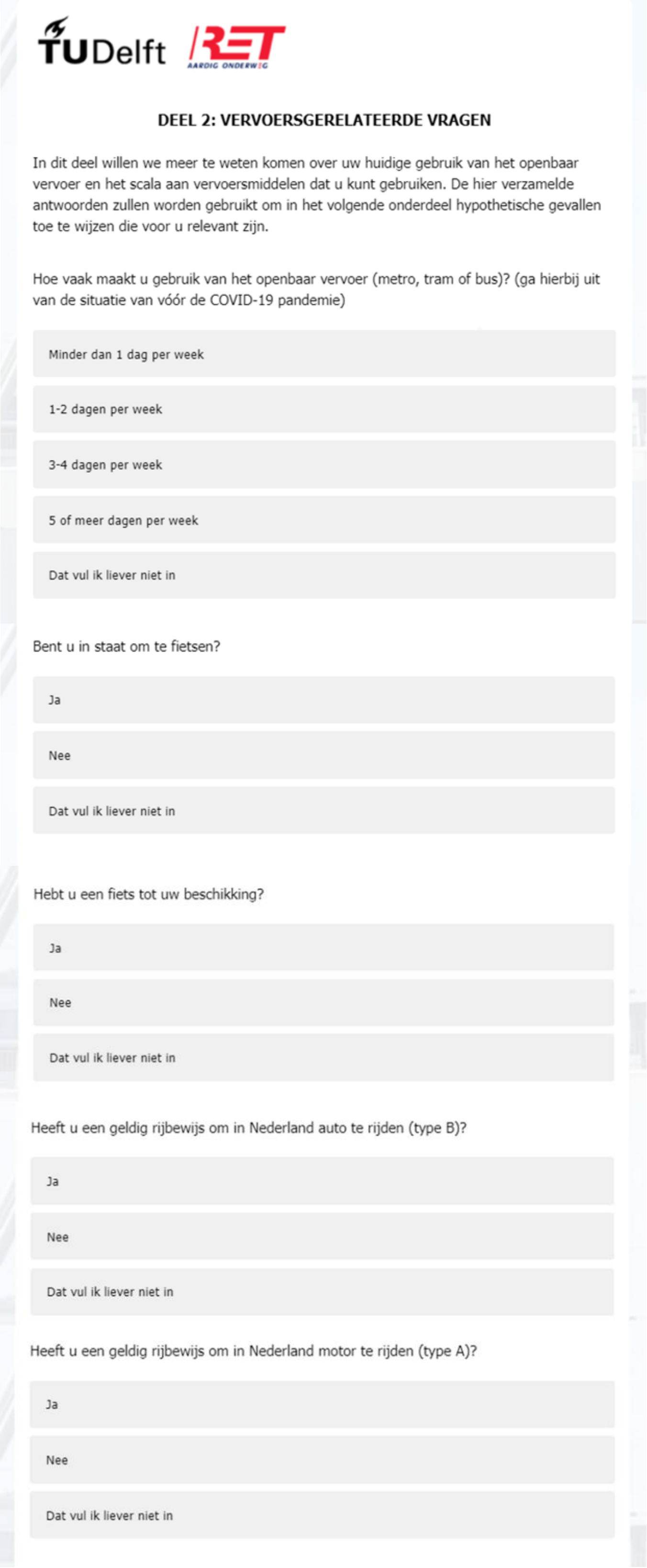


Hoeveel mensen (inclusief uzelf) wonen er in uw huishouden?

- 1 persoon
- 2 personen
- 3 personen
- Meer dan 3 personen
- Dat vul ik liever niet in

Zou u uw bruto jaarinkomen aan willen geven?

- < €10.000
- €10.000 - €30.000
- €30.000 - €50.000
- €50.000 - €100.000
- €100.000 - €200.000
- > €200.000
- Dat vul ik liever niet in



DEEL 2: VERVOERSGERELATEERDE VRAGEN

In dit deel willen we meer te weten komen over uw huidige gebruik van het openbaar vervoer en het scala aan vervoersmiddelen dat u kunt gebruiken. De hier verzamelde antwoorden zullen worden gebruikt om in het volgende onderdeel hypothetische gevallen toe te wijzen die voor u relevant zijn.

Hoe vaak maakt u gebruik van het openbaar vervoer (metro, tram of bus)? (ga hierbij uit van de situatie van vóór de COVID-19 pandemie)

- Minder dan 1 dag per week
- 1-2 dagen per week
- 3-4 dagen per week
- 5 of meer dagen per week
- Dat vul ik liever niet in

Bent u in staat om te fietsen?

- Ja
- Nee
- Dat vul ik liever niet in

Hebt u een fiets tot uw beschikking?

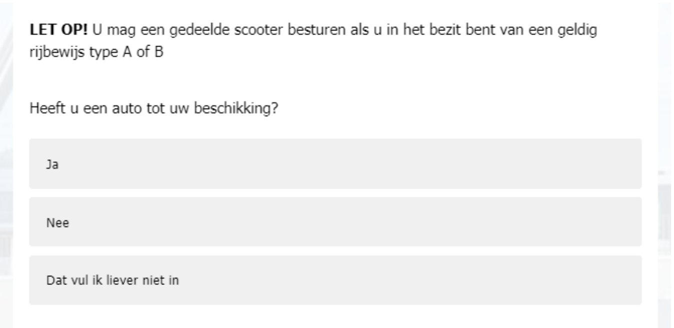
- Ja
- Nee
- Dat vul ik liever niet in

Heeft u een geldig rijbewijs om in Nederland auto te rijden (type B)?

- Ja
- Nee
- Dat vul ik liever niet in

Heeft u een geldig rijbewijs om in Nederland motor te rijden (type A)?

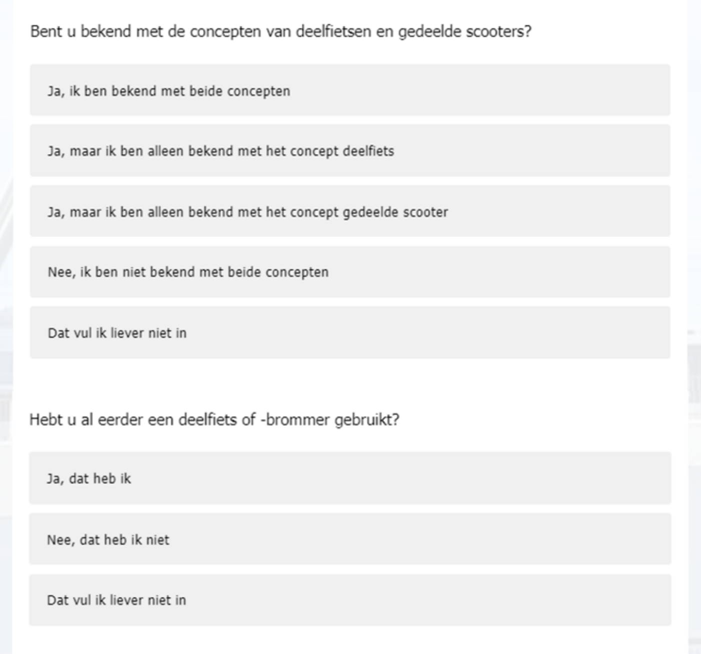
- Ja
- Nee
- Dat vul ik liever niet in



LET OP! U mag een gedeelde scooter besturen als u in het bezit bent van een geldig rijbewijs type A of B

Heeft u een auto tot uw beschikking?

- Ja
- Nee
- Dat vul ik liever niet in

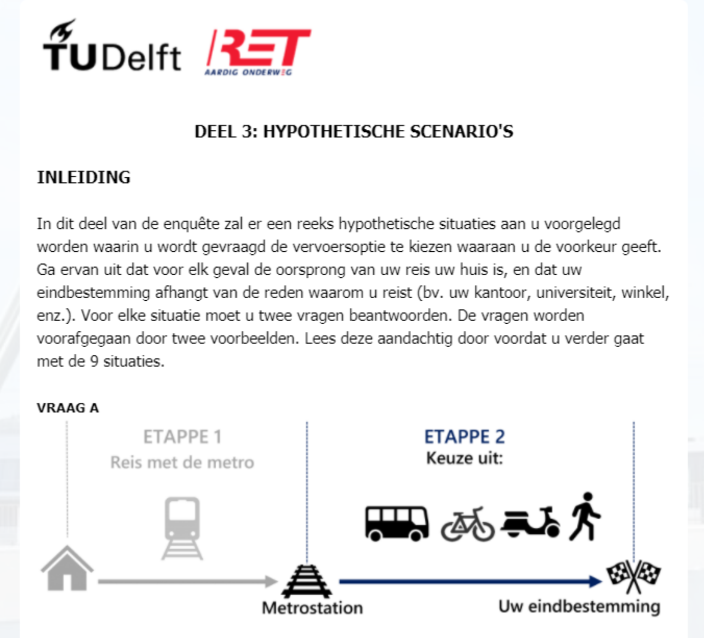


Bent u bekend met de concepten van deelfietsen en gedeelde scooters?

- Ja, ik ben bekend met beide concepten
- Ja, maar ik ben alleen bekend met het concept deelfiets
- Ja, maar ik ben alleen bekend met het concept gedeelde scooter
- Nee, ik ben niet bekend met beide concepten
- Dat vul ik liever niet in

Hebt u al eerder een deelfiets of -brommer gebruikt?

- Ja, dat heb ik
- Nee, dat heb ik niet
- Dat vul ik liever niet in



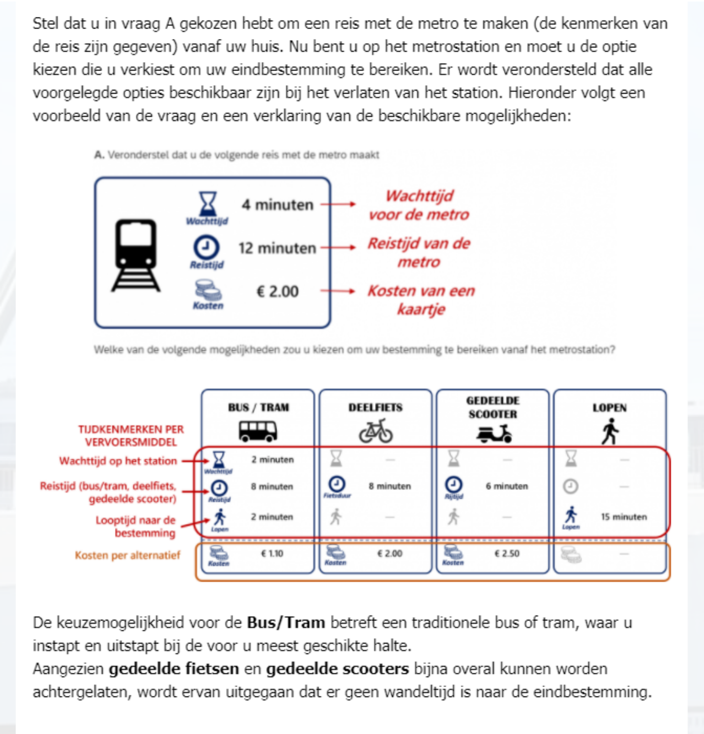
TUDelft RET AARDIG ONDERWEG

DEEL 3: HYPOTHETISCHE SCENARIO'S

INLEIDING

In dit deel van de enquête zal er een reeks hypothetische situaties aan u voorgelegd worden waarin u wordt gevraagd de vervoersoptie te kiezen waaraan u de voorkeur geeft. Ga ervan uit dat voor elk geval de oorsprong van uw reis uw huis is, en dat uw eindbestemming afhangt van de reden waarom u reist (bv. uw kantoor, universiteit, winkel, enz.). Voor elke situatie moet u twee vragen beantwoorden. De vragen worden voorafgegaan door twee voorbeelden. Lees deze aandachtig door voordat u verder gaat met de 9 situaties.

VRAAG A



Stel dat u in vraag A gekozen hebt om een reis met de metro te maken (de kenmerken van de reis zijn gegeven) vanaf uw huis. Nu bent u op het metrostation en moet u de optie kiezen die u verkiest om uw eindbestemming te bereiken. Er wordt verondersteld dat alle voorgelegde opties beschikbaar zijn bij het verlaten van het station. Hieronder volgt een voorbeeld van de vraag en een verklaring van de beschikbare mogelijkheden:

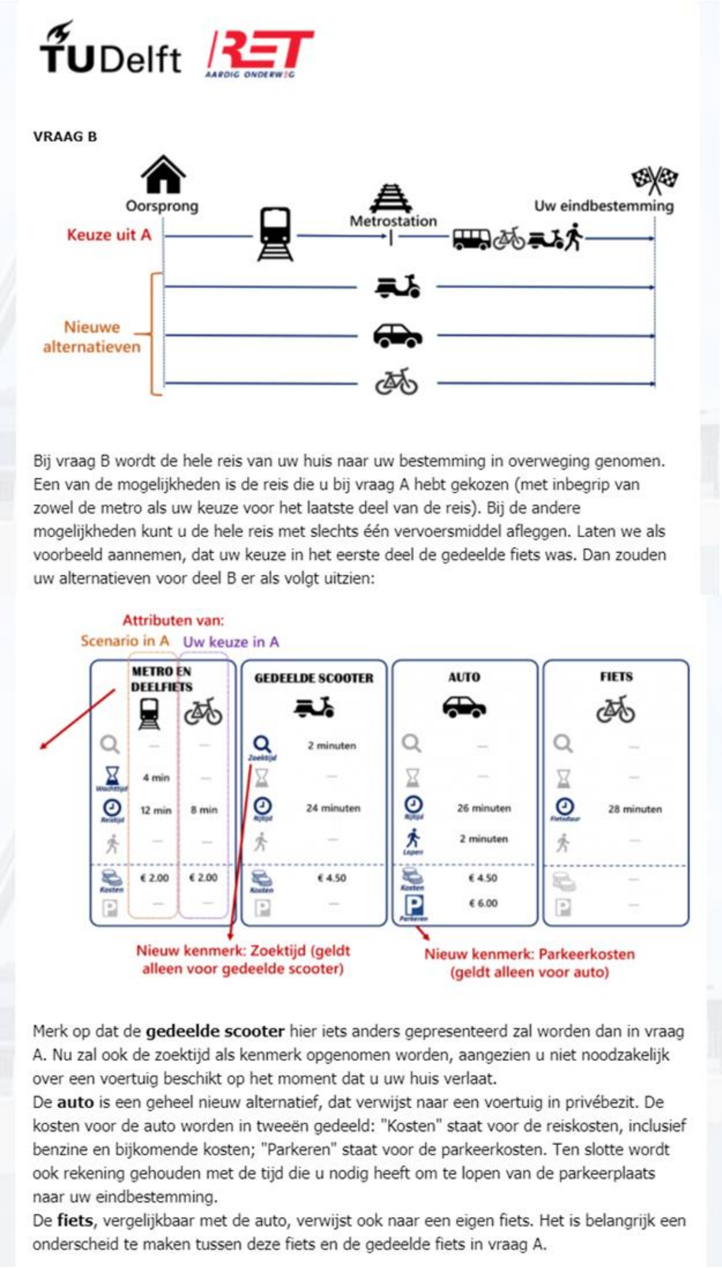
A. Veronderstel dat u de volgende reis met de metro maakt

Wachttijd: 4 minuten → *Wachttijd voor de metro*
Reistijd: 12 minuten → *Reistijd van de metro*
Kosten: € 2.00 → *Kosten van een kaartje*

Welke van de volgende mogelijkheden zou u kiezen om uw bestemming te bereiken vanaf het metrostation?

TIJDKENMERKEN PER VERVOERSMIDDEL	BUS / TRAM	DEELFIETS	GEDEELDE SCOOTER	LOPEN
Wachttijd op het station	Wachttijd: 2 minuten	—	—	—
Reistijd (bus/tram, deelfiets, gedeelde scooter)	Reistijd: 8 minuten	Fietsduur: 8 minuten	Rijtijd: 6 minuten	—
Looptijd naar de bestemming	Lopen: 2 minuten	—	—	Lopen: 15 minuten
Kosten per alternatief	Kosten: € 1.10	Kosten: € 2.00	Kosten: € 2.50	—

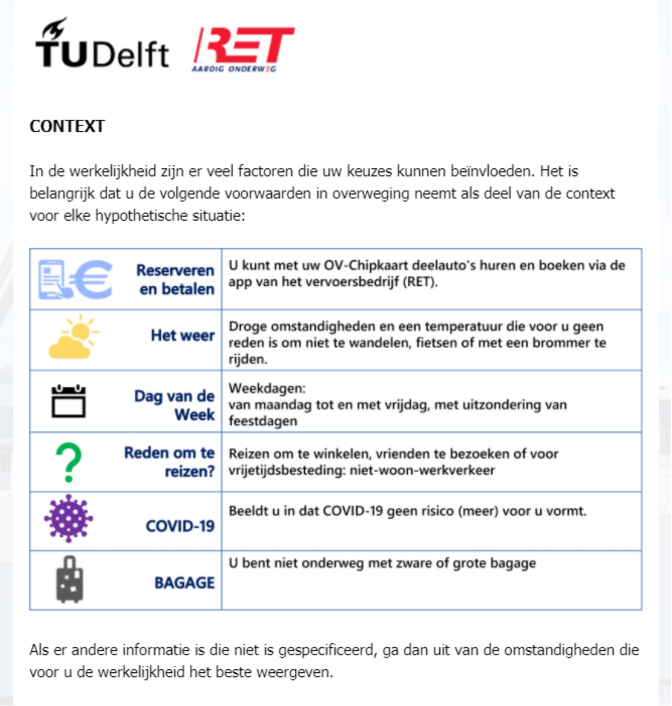
De keuzemogelijkheid voor de **Bus/Tram** betreft een traditionele bus of tram, waar u instapt en uitstapt bij de voor u meest geschikte halte.
Aangezien **gedeelde fietsen** en **gedeelde scooters** bijna overal kunnen worden achtergelaten, wordt ervan uitgegaan dat er geen wandeltijd is naar de eindbestemming.



VRAAG B

Bij vraag B wordt de hele reis van uw huis naar uw bestemming in overweging genomen. Een van de mogelijkheden is de reis die u bij vraag A hebt gekozen (met inbegrip van zowel de metro als uw keuze voor het laatste deel van de reis). Bij de andere mogelijkheden kunt u de hele reis met slechts één vervoersmiddel afleggen. Laten we als voorbeeld aannemen, dat uw keuze in het eerste deel de gedeelde fiets was. Dan zouden uw alternatieven voor deel B er als volgt uitzien:

Merk op dat de **gedeelde scooter** hier iets anders gepresenteerd zal worden dan in vraag A. Nu zal ook de zoektijd als kenmerk opgenomen worden, aangezien u niet noodzakelijk over een voertuig beschikt op het moment dat u uw huis verlaat.
De **auto** is een geheel nieuw alternatief, dat verwijst naar een voertuig in privébezit. De kosten voor de auto worden in tweeën gedeeld: "Kosten" staat voor de reiskosten, inclusief benzine en bijkomende kosten; "Parkeren" staat voor de parkeerkosten. Ten slotte wordt ook rekening gehouden met de tijd die u nodig heeft om te lopen van de parkeerplaats naar uw eindbestemming.
De **fiets**, vergelijkbaar met de auto, verwijst ook naar een eigen fiets. Het is belangrijk een onderscheid te maken tussen deze fiets en de gedeelde fiets in vraag A.



CONTEXT

In de werkelijkheid zijn er veel factoren die uw keuzes kunnen beïnvloeden. Het is belangrijk dat u de volgende voorwaarden in overweging neemt als deel van de context voor elke hypothetische situatie:

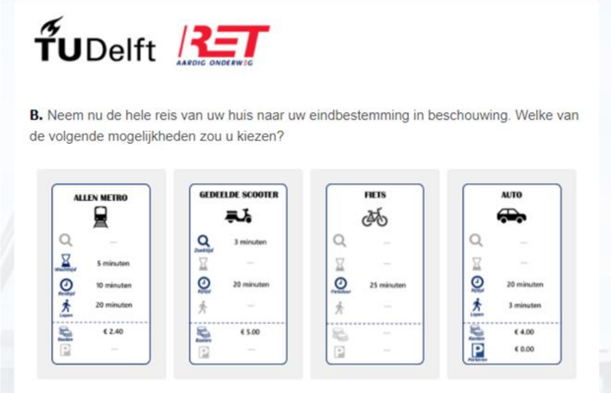
Reserveren en betalen	U kunt met uw OV-Chipkaart deelauto's huren en boeken via de app van het vervoersbedrijf (RET).
Het weer	Droge omstandigheden en een temperatuur die voor u geen reden is om niet te wandelen, fietsen of met een brommer te rijden.
Dag van de Week	Weekdagen: van maandag tot en met vrijdag, met uitzondering van feestdagen
Reden om te reizen?	Reizen om te winkelen, vrienden te bezoeken of voor vrijetijdsbesteding: niet-woon-werkverkeer
COVID-19	Beeldt u in dat COVID-19 geen risico (meer) voor u vormt.
BAGAGE	U bent niet onderweg met zware of grote bagage

Als er andere informatie is die niet is gespecificeerd, ga dan uit van de omstandigheden die voor u de werkelijkheid het beste weergeven.

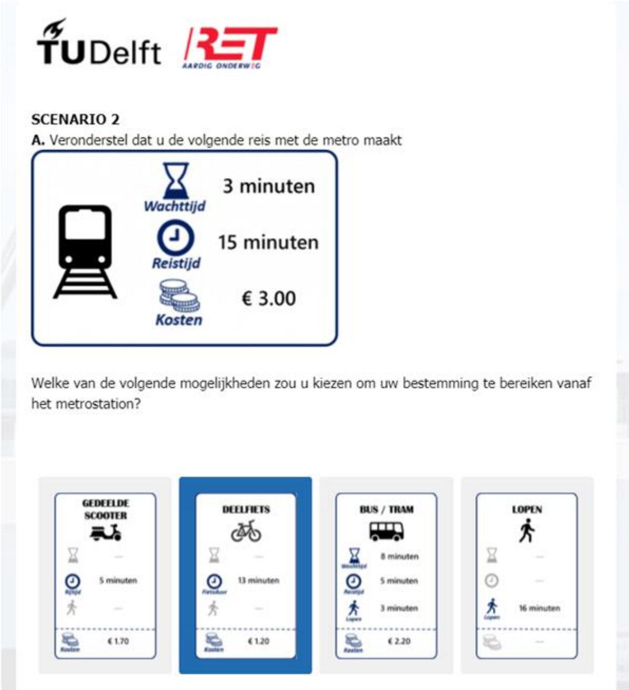
SCENARIO 1

A. Veronderstel dat u de volgende reis met de metro maakt

Welke van de volgende mogelijkheden zou u kiezen om uw bestemming te bereiken vanaf het metrostation?



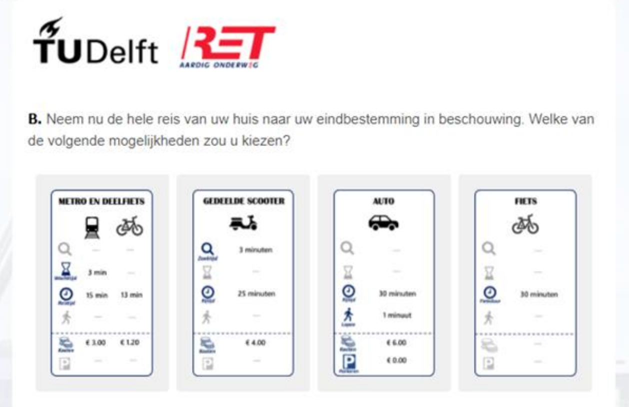
B. Neem nu de hele reis van uw huis naar uw eindbestemming in beschouwing. Welke van de volgende mogelijkheden zou u kiezen?



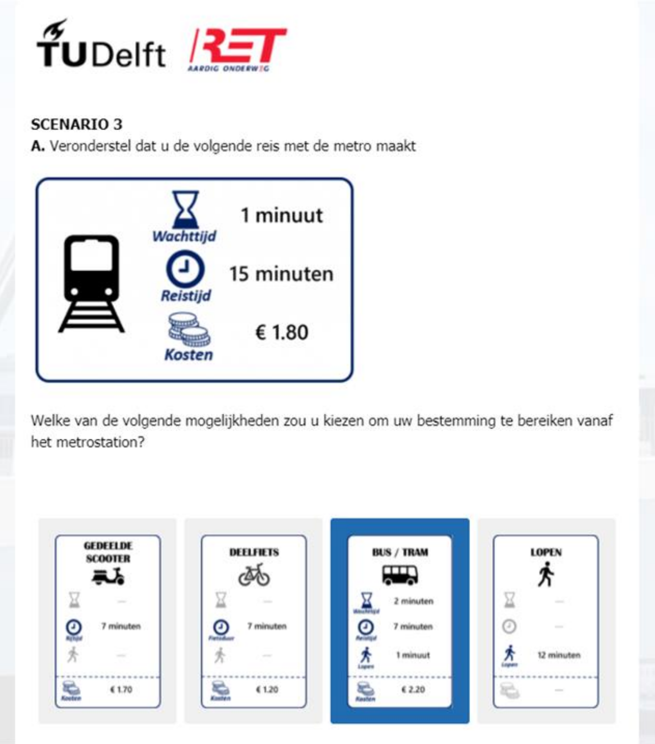
SCENARIO 2

A. Veronderstel dat u de volgende reis met de metro maakt

Welke van de volgende mogelijkheden zou u kiezen om uw bestemming te bereiken vanaf het metrostation?



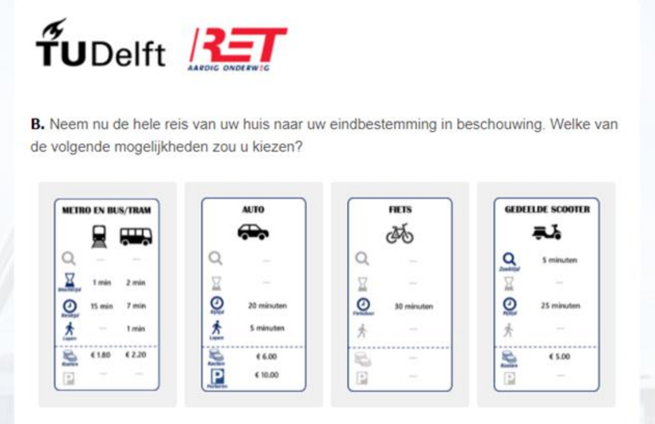
B. Neem nu de hele reis van uw huis naar uw eindbestemming in beschouwing. Welke van de volgende mogelijkheden zou u kiezen?



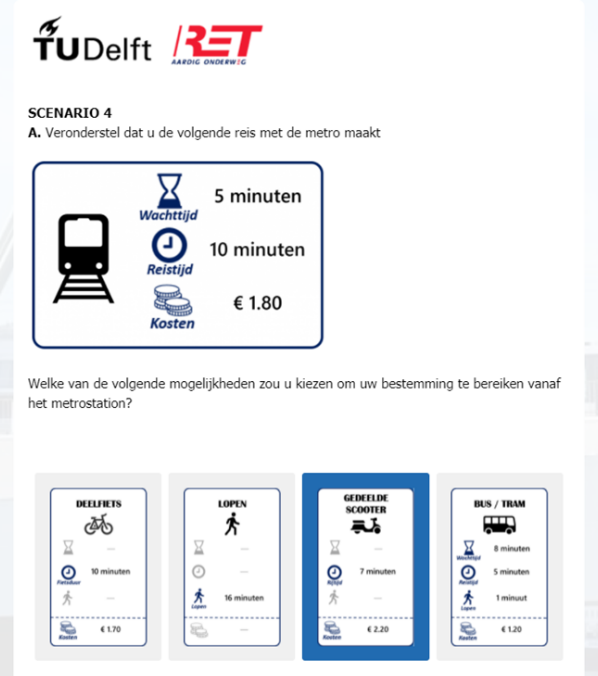
SCENARIO 3

A. Veronderstel dat u de volgende reis met de metro maakt

Welke van de volgende mogelijkheden zou u kiezen om uw bestemming te bereiken vanaf het metrostation?



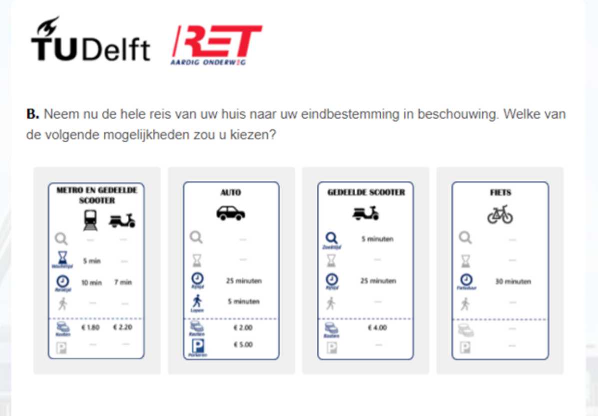
B. Neem nu de hele reis van uw huis naar uw eindbestemming in beschouwing. Welke van de volgende mogelijkheden zou u kiezen?



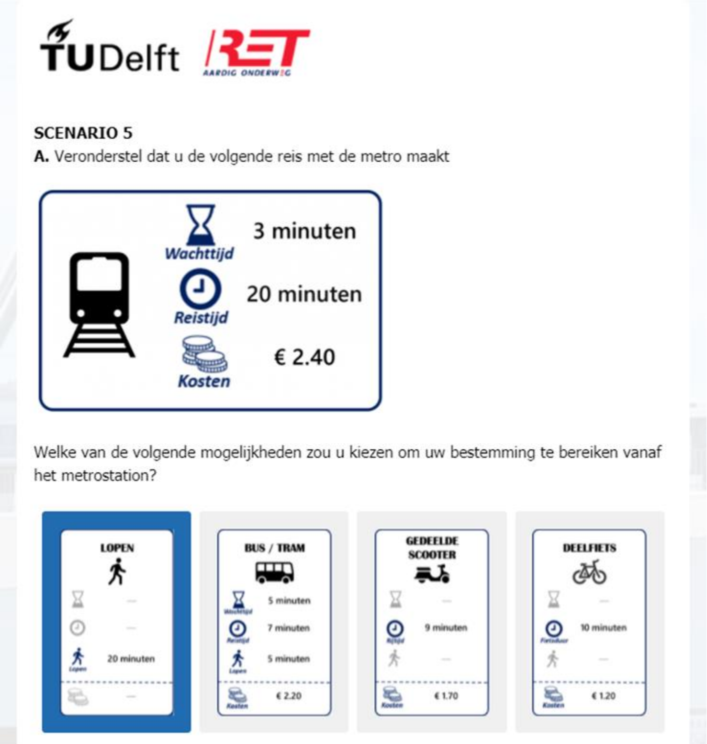
SCENARIO 4

A. Veronderstel dat u de volgende reis met de metro maakt

Welke van de volgende mogelijkheden zou u kiezen om uw bestemming te bereiken vanaf het metrostation?



B. Neem nu de hele reis van uw huis naar uw eindbestemming in beschouwing. Welke van de volgende mogelijkheden zou u kiezen?



SCENARIO 5

A. Veronderstel dat u de volgende reis met de metro maakt

Wachttijd 3 minuten
Reistijd 20 minuten
Kosten € 2.40

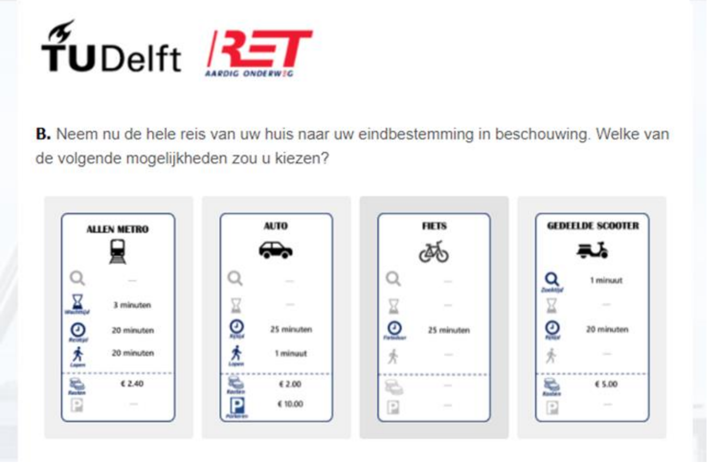
Welke van de volgende mogelijkheden zou u kiezen om uw bestemming te bereiken vanaf het metrostation?

LOPEN
—
—
Lopen 20 minuten
—

BUS / TRAM
Wachttijd 5 minuten
Reistijd 7 minuten
Lopen 5 minuten
Kosten € 2.20

GEDEELDE SCOOTER
—
Rijtijd 9 minuten
—
Kosten € 1.70

DEELFIETS
—
Fietsduur 10 minuten
—
Kosten € 1.20



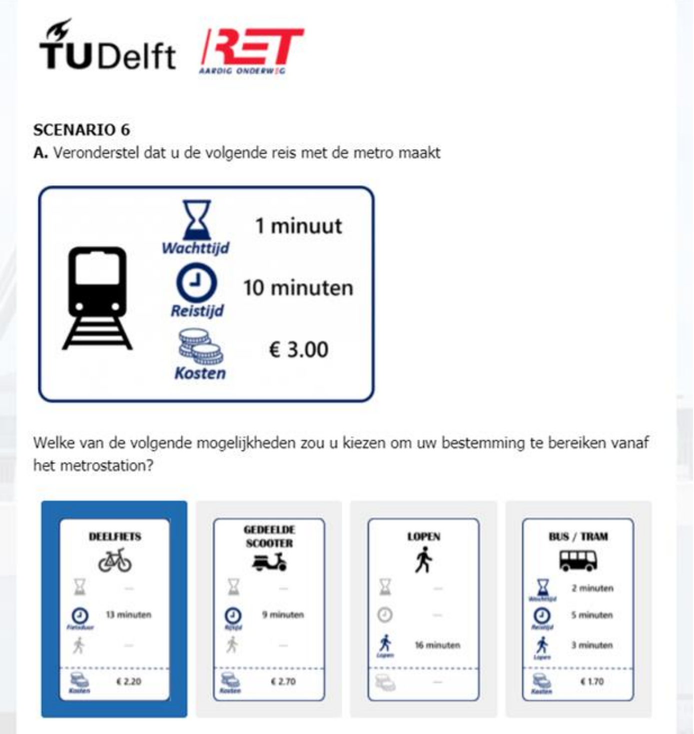
B. Neem nu de hele reis van uw huis naar uw eindbestemming in beschouwing. Welke van de volgende mogelijkheden zou u kiezen?

ALLEN METRO
—
Wachttijd 3 minuten
Reistijd 20 minuten
Lopen 20 minuten
Kosten € 2.40
—

AUTO
—
—
Rijtijd 25 minuten
Lopen 1 minuut
Kosten € 2.00
Parkeren € 10.00

FIETS
—
—
Fietsduur 25 minuten
—
—
—

GEDEELDE SCOOTER
Zoektijd 1 minuut
—
Rijtijd 20 minuten
—
Kosten € 5.00
—



SCENARIO 6

A. Veronderstel dat u de volgende reis met de metro maakt

Wachttijd 1 minuut
Reistijd 10 minuten
Kosten € 3.00

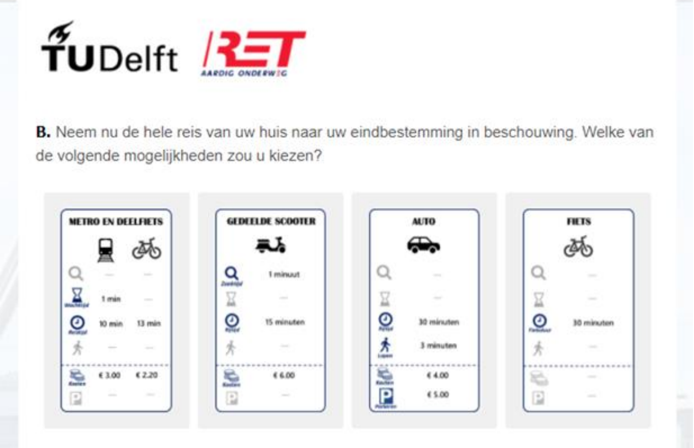
Welke van de volgende mogelijkheden zou u kiezen om uw bestemming te bereiken vanaf het metrostation?

DEELFIETS
—
Fietsduur 13 minuten
—
Kosten € 2.20

GEDEELDE SCOOTER
—
Rijtijd 9 minuten
—
Kosten € 2.70

LOPEN
—
—
Lopen 16 minuten
—

BUS / TRAM
Wachttijd 2 minuten
Reistijd 5 minuten
Lopen 3 minuten
Kosten € 1.70



B. Neem nu de hele reis van uw huis naar uw eindbestemming in beschouwing. Welke van de volgende mogelijkheden zou u kiezen?

METRO EN DEELFIETS
— —
Wachttijd 1 min —
Reistijd 10 min 13 min
— —
Kosten € 3.00 € 2.20
— —

GEDEELDE SCOOTER
Zoektijd 1 minuut
—
Rijtijd 15 minuten
—
Kosten € 6.00
—

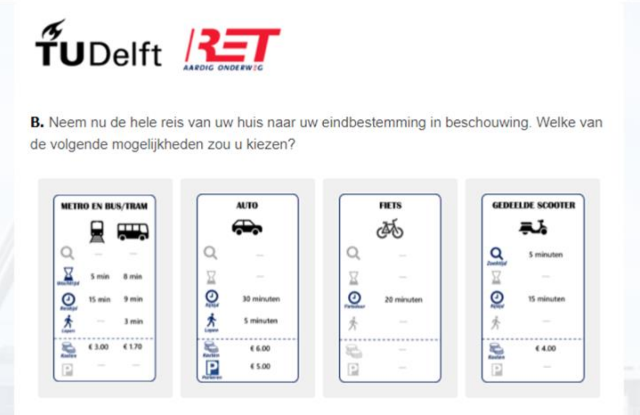
AUTO
—
—
Rijtijd 30 minuten
Lopen 3 minuten
Kosten € 4.00
Parkeren € 5.00

FIETS
—
—
Fietsduur 30 minuten
—
—
—


SCENARIO 7

A. Veronderstel dat u de volgende reis met de metro maakt

Welke van de volgende mogelijkheden zou u kiezen om uw bestemming te bereiken vanaf het metrostation?

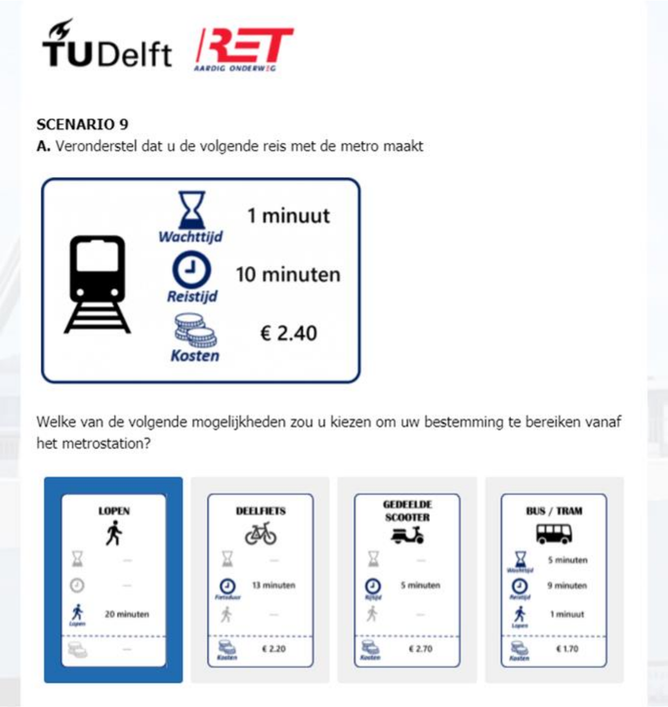

B. Neem nu de hele reis van uw huis naar uw eindbestemming in beschouwing. Welke van de volgende mogelijkheden zou u kiezen?


SCENARIO 8

A. Veronderstel dat u de volgende reis met de metro maakt

Welke van de volgende mogelijkheden zou u kiezen om uw bestemming te bereiken vanaf het metrostation?

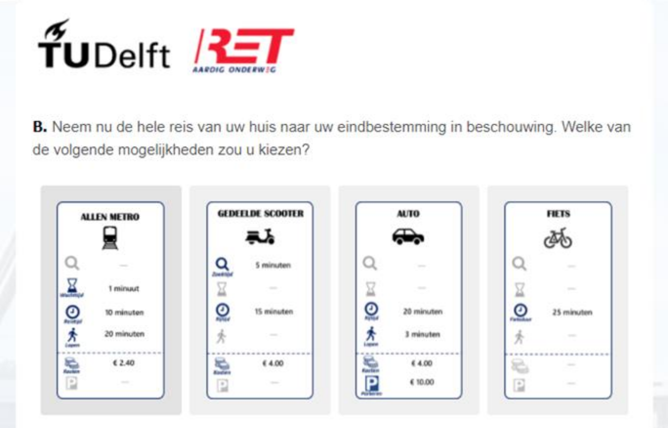

B. Neem nu de hele reis van uw huis naar uw eindbestemming in beschouwing. Welke van de volgende mogelijkheden zou u kiezen?



SCENARIO 9

A. Veronderstel dat u de volgende reis met de metro maakt

Welke van de volgende mogelijkheden zou u kiezen om uw bestemming te bereiken vanaf het metrostation?



B. Neem nu de hele reis van uw huis naar uw eindbestemming in beschouwing. Welke van de volgende mogelijkheden zou u kiezen?

U wordt doorgestuurd. Even geduld a.u.b.

Klik hier wanneer u niet automatisch wordt doorgestuurd.

B. MNL Model

B.1 Biogeme syntax

MNL Base Model

```
# MNL Model for the whole trip - Base for other models
# Separated ASC for Metro and egress modes

import pandas as pd
import biogeme.database as db
import biogeme.biogeme as bio
import biogeme.models as models
from biogeme.expressions import Beta

df = pd.read_csv('data.csv', skipinitialspace=True, index_col=0) #
read data
database = db.Database('data', df) # create database for biogeme

globals().update(database.variables) # define headers of columns
as variables

# Exclude cases in which either or B was not answered
exclude = ((A == 0) + (B == 0)) >= 1
database.remove(exclude)

# Parameters to be estimated
# Alternative specific constants
ASC_METRO = Beta('ASC_METRO', 0, None, None, 0)
ASC_BT = Beta('ASC_BT', 0, None, None, 0)
ASC_SB = Beta('ASC_SB', 0, None, None, 0)
ASC_SM_E = Beta('ASC_SM_E', 0, None, None, 0)
ASC_SM = Beta('ASC_SM', 0, None, None, 0)
ASC_BIKE = Beta('ASC_BIKE', 0, None, None, 0)
ASC_CAR = Beta('ASC_CAR', 0, None, None, 1)

# Parameters to be estimated
# Betas
# Main
B_METRO_WAIT = Beta('B_METRO_WAIT', 0, None, None, 0)
B_MAIN_TIME = Beta('B_MAIN_TIME', 0, None, None, 0)
B_MAIN_COST = Beta('B_MAIN_COST', 0, None, None, 0)

# Egress
B_EGRESS_TIME = Beta('B_EGRESS_TIME', 0, None, None, 0)
B_WALK = Beta('B_WALK', 0, None, None, 0)
B_EGRESS_COST = Beta('B_EGRESS_COST', 0, None, None, 0)

# New variables for availability of alternatives
metro_bt = 1
metro_sb = SharedBike
metro_sm = SharedMoped
metro_walk = 1

# Specification of utility functions
# Metro alternatives
V1 = ASC_METRO + ASC_BT + B_METRO_WAIT*metro_wt +
B_MAIN_TIME*metro_vt + B_MAIN_COST*metro_cost +
B_EGRESS_TIME*(bt_vt + bt_wt) + B_WALK*bt_walk +
B_EGRESS_COST*bt_cost # Metro & BT

V2 = ASC_METRO + ASC_SB + B_METRO_WAIT*metro_wt +
B_MAIN_TIME*metro_vt + B_MAIN_COST*metro_cost +
B_EGRESS_TIME*sbike_vt + B_EGRESS_COST*sbike_cost # Metro
& Shared Bike

V3 = ASC_METRO + ASC_SM_E + B_METRO_WAIT*metro_wt +
B_MAIN_TIME*metro_vt + B_MAIN_COST*metro_cost +
B_EGRESS_TIME*smoped_vt + B_EGRESS_COST*smoped_cost #
Metro & Shared Bike

V4 = ASC_METRO + B_METRO_WAIT*metro_wt +
B_MAIN_TIME*metro_vt + B_MAIN_COST*metro_cost + \
  B_WALK*walk_t

# Other alternatives
V5 = ASC_SM + B_WALK*smoped2_search +
B_MAIN_TIME*smoped2_vt + B_MAIN_COST*smoped2_cost
V6 = ASC_CAR + B_MAIN_TIME*car_vt + B_WALK*car_walk +
B_MAIN_COST*(car_cost + car_park)
V7 = ASC_BIKE + B_MAIN_TIME*bike_vt

# Associating utility functions with alternatives
V = {1: V1,
    2: V2,
    3: V3,
    4: V4,
    5: V5,
    6: V6,
    7: V7}

# Availability of alternatives
av = {1: metro_bt,
     2: metro_sb,
     3: metro_sm,
     4: metro_walk,
     5: SharedMoped,
     6: Car,
     7: Bike}

# Defining choice model and creating BIOGEME object
logprob = models.loglogit(V, av, B)
biogeme = bio.BIOGEME(database, logprob)
biogeme.modelName = 'MNL_Base'
results = biogeme.estimate()

# To get statistics
gs = results.getGeneralStatistics()
pandasResults = results.getEstimatedParameters()
correlationResults = results.getCorrelationResults()
```

```
display(gs)
```

```
display(pandasResults)
display(correlationResults)
```

MNL with interaction effects (2 levels)

Example of MNL model to capture interaction effects: Variable coded in two levels, interaction with ASC. Other interaction effects varied in two levels are coded analogously.

```
# MNL Model
# Purpose effect on ASC --> Dummy coded
import pandas as pd
import biogeme.database as db
import biogeme.biogeme as bio
import biogeme.models as models
from biogeme.expressions import Beta

df = pd.read_csv('data.csv', skipinitialspace=True, index_col=0)  #
read data
database = db.Database('data', df)  # create database for biogeme

globals().update(database.variables) # define headers of columns
as variables

# Exclude cases in which either A or B was not answered, and
those in which familiarity was not specified
exclude = ((A == 0) + (B == 0)) >= 1
database.remove(exclude)

# New variables effects coding trip purpose
Commute = (Context == 1) # 1 if Commuting, 0 for other purposes

# Parameters to be estimated
# Alternative specific constants
ASC_METRO = Beta('ASC_METRO', 0, None, None, 0)
ASC_METRO_C = Beta('ASC_METRO_C', 0, None, None, 0)

ASC_BT = Beta('ASC_BT', 0, None, None, 0)
ASC_BT_C = Beta('ASC_BT_C', 0, None, None, 0)

ASC_SB = Beta('ASC_SB', 0, None, None, 0)
ASC_SB_C = Beta('ASC_SB_C', 0, None, None, 0)

ASC_SM_E = Beta('ASC_SM_E', 0, None, None, 0)
ASC_SM_E_C = Beta('ASC_SM_E_C', 0, None, None, 0)

ASC_SM = Beta('ASC_SM', 0, None, None, 0)
ASC_SM_C = Beta('ASC_SM_C', 0, None, None, 0)

ASC_BIKE = Beta('ASC_BIKE', 0, None, None, 0)
ASC_BIKE_C = Beta('ASC_BIKE_C', 0, None, None, 0)

ASC_CAR = Beta('ASC_CAR', 0, None, None, 1)

# Parameters to be estimated
# Main
B_METRO_WAIT = Beta('B_METRO_WAIT', 0, None, None, 0)
B_MAIN_TIME = Beta('B_MAIN_TIME', 0, None, None, 0)
B_MAIN_COST = Beta('B_MAIN_COST', 0, None, None, 0)

# Egress
B_EGRESS_TIME = Beta('B_EGRESS_TIME', 0, None, None, 0)
B_WALK = Beta('B_WALK', 0, None, None, 0)
B_EGRESS_COST = Beta('B_EGRESS_COST', 0, None, None, 0)

# New variables for availability of alternatives
metro_bt = 1
metro_sb = SharedBike
metro_sm = SharedMoped
metro_walk = 1

# Specificacion of utility functions
# Metro alternatives
V1 = ASC_METRO + ASC_METRO_C*Commute + ASC_BT +
ASC_BT_C*Commute + B_METRO_WAIT*metro_wt +
B_MAIN_TIME*metro_vt + B_MAIN_COST*metro_cost +
B_EGRESS_TIME*(bt_vt + bt_wt) + B_WALK*bt_walk +
B_EGRESS_COST*bt_cost # Metro & BT

V2 = ASC_METRO + ASC_METRO_C*Commute + ASC_SB +
ASC_SB_C*Commute + B_METRO_WAIT*metro_wt +
B_MAIN_TIME*metro_vt + B_MAIN_COST*metro_cost +
B_EGRESS_TIME*sbike_vt + B_EGRESS_COST*sbike_cost # Metro
& Shared Bike

V3 = ASC_METRO + ASC_METRO_C*Commute + ASC_SM_E +
ASC_SM_E_C*Commute + \
   B_METRO_WAIT*metro_wt + B_MAIN_TIME*metro_vt +
B_MAIN_COST*metro_cost + \
   B_EGRESS_TIME*smoped_vt + B_EGRESS_COST*smoped_cost #
Metro & Shared Bike

V4 = ASC_METRO + ASC_METRO_C*Commute + \
   B_METRO_WAIT*metro_wt + B_MAIN_TIME*metro_vt +
B_MAIN_COST*metro_cost + \
   B_WALK*walk_t

# Other alternatives
V5 = ASC_SM + ASC_SM_C*Commute + B_WALK*smoped2_search
+ B_MAIN_TIME*smoped2_vt + B_MAIN_COST*smoped2_cost
V6 = ASC_CAR + B_MAIN_TIME*car_vt + B_WALK*car_walk +
B_MAIN_COST*(car_cost + car_park)
V7 = ASC_BIKE + ASC_BIKE_C*Commute + B_MAIN_TIME*bike_vt

# Associating utility functions with alternatives
V = {1: V1,
     2: V2,
     3: V3,
     4: V4,
     5: V5,
     6: V6,
     7: V7}

# Availability of alternatives
av = {1: metro_bt,
      2: metro_sb,
      3: metro_sm,
      4: metro_walk,
      5: SharedMoped,
      6: Car,
      7: Bike}

# Defining choice model and creating BIOGEME object
logprob = models.loglogit(V, av, B)
biogeme = bio.BIOGEME(database, logprob)
biogeme.modelName = 'MNL_Purpose-ASC'
results = biogeme.estimate()

# To get statistics
gs = results.getGeneralStatistics()
pandasResults = results.getEstimatedParameters()
```

```
correlationResults = results.getCorrelationResults()

display(gs)
display(pandasResults)
display(correlationResults)
```

MNL with interaction effects (3 levels)

Example of MNL model to capture interaction effects: Variable coded in three levels, interaction with cost parameters. Other interaction effects varied in three levels are coded analogously.

```
# MNL Model for the whole trip
# Age effects in beta-cost
import pandas as pd
import biogeme.database as db
import biogeme.biogeme as bio
import biogeme.models as models
from biogeme.expressions import Beta

df = pd.read_csv('data.csv', skipinitialspace=True, index_col=0)
database = db.Database('data', df)  # create database for biogeme

globals().update(database.variables) # define headers as
variables

# Exclude cases in which either or B was not answered
exclude = ((A == 0) + (B == 0) + (Age > 16)) >= 1
database.remove(exclude)

# New variable: Age --- Dummy coded
#          Age 1   Age 2
# <=35        1      0
# 35-65       0      1
# Base (>65)  0      0

Age1 = (Age < 11)
Age2 = (((Age >= 11) + (Age < 14)) == 2)

# Parameters to be estimated
# Alternative specific constants
ASC_METRO = Beta('ASC_METRO', 0, None, None, 0)
ASC_BT = Beta('ASC_BT', 0, None, None, 0)
ASC_SB = Beta('ASC_SB', 0, None, None, 0)
ASC_SM_E = Beta('ASC_SM_E', 0, None, None, 0)
ASC_SM = Beta('ASC_SM', 0, None, None, 0)
ASC_BIKE = Beta('ASC_BIKE', 0, None, None, 0)
ASC_CAR = Beta('ASC_CAR', 0, None, None, 1)

# Betas
# Time
B_METRO_WAIT = Beta('B_METRO_WAIT', 0, None, None, 0)
B_MAIN_TIME = Beta('B_MAIN_TIME', 0, None, None, 0)
B_WALK = Beta('B_WALK', 0, None, None, 0)
B_EGRESS_TIME = Beta('B_EGRESS_TIME', 0, None, None, 0)

# Cost
B_MAIN_COST = Beta('B_MAIN_COST', 0, None, None, 0)
B_MAIN_COST_A1 = Beta('B_MAIN_COST_A1', 0, None, None, 0)
B_MAIN_COST_A2 = Beta('B_MAIN_COST_A2', 0, None, None, 0)

B_EGRESS_COST = Beta('B_EGRESS_COST', 0, None, None, 0)
B_EGRESS_COST_A1 = Beta('B_EGRESS_COST_A1', 0, None, None,
0)
B_EGRESS_COST_A2 = Beta('B_EGRESS_COST_A2', 0, None, None,
0)

# New variables for availability of alternatives
metro_bt = 1
metro_sb = SharedBike
metro_sm = SharedMoped
metro_walk = 1

# Specificacion of utility functions
# Metro alternativese
V1 = ASC_METRO + ASC_BT + B_METRO_WAIT*metro_wt +
B_MAIN_TIME*metro_vt + (B_MAIN_COST +
B_MAIN_COST_A1*Age1 + B_MAIN_COST_A2*Age2)*metro_cost +
B_EGRESS_TIME*(bt_vt + bt_wt) + B_WALK*bt_walk +
(B_EGRESS_COST + B_EGRESS_COST_A1*Age1 +
B_EGRESS_COST_A2*Age2)*bt_cost # Metro & BT

V2 = ASC_METRO + ASC_SB + B_METRO_WAIT*metro_wt +
B_MAIN_TIME*metro_vt + (B_MAIN_COST +
B_MAIN_COST_A1*Age1 + B_MAIN_COST_A2*Age2)*metro_cost +
B_EGRESS_TIME*sbike_vt + (B_EGRESS_COST +
B_EGRESS_COST_A1*Age1 +
B_EGRESS_COST_A2*Age2)*sbike_cost # Metro & Shared Bike

V3 = ASC_METRO + ASC_SM_E + B_METRO_WAIT*metro_wt +
B_MAIN_TIME*metro_vt + (B_MAIN_COST +
B_MAIN_COST_A1*Age1 + B_MAIN_COST_A2*Age2)*metro_cost +
B_EGRESS_TIME*smoped_vt + (B_EGRESS_COST +
B_EGRESS_COST_A1*Age1 +
B_EGRESS_COST_A2*Age2)*smoped_cost # Metro & Shared Bike

V4 = ASC_METRO + B_METRO_WAIT*metro_wt +
B_MAIN_TIME*metro_vt + (B_MAIN_COST +
B_MAIN_COST_A1*Age1 + B_MAIN_COST_A2*Age2)*metro_cost +
B_WALK*walk_t

# Other alternatives
V5 = ASC_SM + B_WALK*smoped2_search +
B_MAIN_TIME*smoped2_vt + (B_MAIN_COST +
B_MAIN_COST_A1*Age1 +
B_MAIN_COST_A2*Age2)*smoped2_cost

V6 = ASC_CAR + B_MAIN_TIME*car_vt + B_WALK*car_walk +
  (B_MAIN_COST + B_MAIN_COST_A1*Age1 +
B_MAIN_COST_A2*Age2)*(car_cost + car_park)

V7 = ASC_BIKE + B_MAIN_TIME*bike_vt

# Associating utility functions with alternatives
V = {1: V1,
   2: V2,
   3: V3,
   4: V4,
   5: V5,
   6: V6,
   7: V7}

# Availability of alternatives
av = {1: metro_bt,
    2: metro_sb,
    3: metro_sm,
    4: metro_walk,
    5: SharedMoped,
    6: Car,
    7: Bike}
```

```
# Defining choice model and creating BIOGEME object
logprob = models.loglogit(V, av, B)
biogeme = bio.BIOGEME(database, logprob)
biogeme.modelName = 'MNL_Age-Costs'
results = biogeme.estimate
```

B.2 Results – Interaction effects

Gender

INTERACTIONS	*Gender*				
Alternative specific constants			*Rho-square*		*0.172*
ASC_METRO	Base ASC_METRO (gender: female)	utils	-0.642	0.202	-3.18
ASC_METRO_M	Delta ASC_METRO_M if gender: male	utils	-0.496	0.122	-4.06
ASC_BT	Base ASC_BT (gender: female)	utils	0.621	0.234	2.65
ASC_BT_M	Delta ASC_BT_M if gender female	utils	0.157	0.110	1.43
ASC_SB	Base ASC_SB (gender: female)	utils	-0.743	0.251	-2.96
ASC_SB_M	Delta ASC_SB_M if gender: male	utils	-0.341	0.181	-1.88
ASC_SM_E	Base ASC_SM_E (gender: female)	utils	-1.210	0.275	-4.39
ASC_SM_E_M	Delta ASC_SM_E_M if gender female	utils	0.603	0.194	3.11
ASC_WALK	Base ASC_WALK (gender: female)	utils	-0.210	0.130	-1.62
ASC_WALK_M	Delta ASC_WALK_M if gender: male	utils	-0.210	0.130	-1.62
ASC_SM	Base ASC_SM (gender: female)	utils	-1.290	0.101	-12.70
ASC_SM_M	Delta ASC_SM_M if gender female	utils	-0.210	0.130	-1.62
ASC_BIKE	Base ASC_BIKE (gender: female)	utils	-0.153	0.117	-1.31
ASC_BIKE_M	Delta ASC_BIKE_M if gender: male	utils	-0.265	0.100	-2.64
Cost parameters			*Rho-square*		*0.17*
B_MAIN_COST	Base B_MAIN_COST (gender: female)	utils/€	-0.108	0.012	-9.05
B_MAIN_COST_M	Delta B_MAIN_COST_M if gender female	utils/€	0.032	0.011	3.02
B_EGRESS_COST	Base B_EGRESS_COST (gender: female)	utils/€	-0.411	0.081	-5.10
B_EGRESS_COST_M	Delta B_EGRESS_COST_M if gender: male	utils/€	-0.037	0.040	-0.92
Time parameters			*Rho-square*		*0.17*
B_EGRESS_TIME	Base B_EGRESS_TIME (gender: female)	utils/min	-0.039	0.013	-3.03
B_EGRESS_TIME_M	Delta B_EGRESS_TIME_M if gender: male	utils/min	-0.001	0.012	-0.06
B_MAIN_TIME	Base B_MAIN_TIME (gender: female)	utils/min	-0.038	0.006	-6.37
B_MAIN_TIME_M	Delta B_MAIN_TIME_M if gender female	utils/min	0.011	0.008	1.36
B_WALK	Base B_WALK (gender: female)	utils/min	-0.061	0.011	-5.66
B_WALK_M	Delta B_WALK_M if gender: male	utils/min	-0.006	0.009	-0.69
B_METRO_WAIT	Base B_METRO_WAIT (gender: female)	utils/min	-0.013	0.027	-0.47
B_METRO_WAIT_M	Delta B_METRO_WAIT_M if gender female	utils/min	-0.005	0.036	-0.13

Legend: highlighted green: significant at 95% confidence interval; highlighted blue: significant at 99% confidence interval

Trip purpose

INTERACTIONS	*Trip purpose*				
Alternative specific constants				*Rho-square*	*0.171*
ASC_METRO	Base ASC_METRO (trip purpose different to commute)	utils	-0.796	0.201	-3.96
ASC_METRO_C	Delta ASC_METRO_C if purpose is commute	utils	-0.120	0.120	-1.00
ASC_BT	Base ASC_BT (trip purpose different to commute)	utils	0.524	0.237	2.22
ASC_BT_C	Delta ASC_BT_C if purpose is commute	utils	0.300	0.106	2.83
ASC_SB	Base ASC_SB (trip purpose different to commute)	utils	-1.090	0.259	-4.20
ASC_SB_C	Delta ASC_SB_C if purpose is commute	utils	0.437	0.169	2.59
ASC_SM_E	Base ASC_SM_E (trip purpose different to commute)	utils	-1.030	0.273	-3.76
ASC_SM_E_C	Delta ASC_SM_E_C if purpose is commute	utils	0.173	0.193	0.90
ASC_WALK	Base ASC_WALK (trip purpose different to commute)	utils	0.173	0.193	0.90
ASC_WALK_C	Delta ASC_WALK_C if purpose is commute	utils	0.173	0.193	0.90
ASC_SM	Base ASC_SM (trip purpose different to commute)	utils	-1.400	0.102	-13.80
ASC_SM_C	Delta ASC_SM_C if purpose is commute	utils	0.036	0.129	0.28
ASC_BIKE	Base ASC_BIKE (trip purpose different to commute)	utils	-0.297	0.117	-2.54
ASC_BIKE_C	Delta ASC_BIKE_C if purpose is commute	utils	0.048	0.100	0.48
Cost parameters				*Rho-square*	*0.171*
B_MAIN_COST	Base B_MAIN_COST (trip purpose different to commute)	utils/€	-0.094	0.012	-8.05
B_MAIN_COST_C	Delta B_MAIN_COST_C if purpose is commute	utils/€	0.001	0.011	0.13
B_EGRESS_COST	Base B_EGRESS_COST (trip purpose different to commute)	utils/€	-0.481	0.082	-5.84
B_EGRESS_COST_C	Delta B_EGRESS_COST_C if purpose is commute	utils/€	0.104	0.039	2.64
Time parameters				*Rho-square*	*0.171*
B_EGRESS_TIME	Base B_EGRESS_TIME (trip purpose different to commute)	utils/min	-0.039	0.014	-2.89
B_EGRESS_TIME_C	Delta B_EGRESS_TIME_C if purpose is commute	utils/min	0.000	0.012	0.01
B_MAIN_TIME	Base B_MAIN_TIME (trip purpose different to commute)	utils/min	-0.031	0.006	-4.92
B_MAIN_TIME_C	Delta B_MAIN_TIME_C if purpose is commute	utils/min	-0.006	0.008	-0.76
B_WALK	Base B_WALK (trip purpose different to commute)	utils/min	-0.053	0.011	-4.83
B_WALK_C	Delta B_WALK_C if purpose is commute	utils/min	-0.023	0.009	-2.44
B_METRO_WAIT	Base B_METRO_WAIT (trip purpose different to commute)	utils/min	-0.031	0.028	-1.12
B_METRO_WAIT_C	Delta B_METRO_WAIT_C if purpose is commute	utils/min	0.035	0.035	1.00

Legend: highlighted green: significant at 95% confidence interval; highlighted blue: significant at 99% confidence interval

Age

Categories	**Base**	**A1**	**A2**
3	> 65 years of age	<= 35 years of age	35-65 years of age

INTERACTIONS	*Age*				
Alternative specific constants			*Rho-square*		*0.188*
ASC_METRO	Base ASC_METRO: When Age is 65 or more	utils	-0.606	0.227	-2.68
ASC_METRO_A1	Delta ASC_METRO for group A1	utils	-0.275	0.177	-1.55
ASC_METRO_A2	Delta ASC_METRO for group A2	utils	-0.323	0.152	-2.13
ASC_BT	Base ASC_BT: When Age is 65 or more	utils	1.130	0.248	4.57
ASC_BT_A1	Delta ASC_BT for group A1	utils	-0.836	0.157	-5.34
ASC_BT_A2	Delta ASC_BT for group A2	utils	-0.541	0.122	-4.45
ASC_SB	Base ASC_SB: When Age is 65 or more	utils	-1.970	0.365	-5.40
ASC_SB_A1	Delta ASC_SB for group A1	utils	1.470	0.317	4.62
ASC_SB_A2	Delta ASC_SB for group A2	utils	1.240	0.302	4.10
ASC_SM_E	Base ASC_SM_E: When Age is 65 or more	utils	-1.490	0.343	-4.36
ASC_SM_E_A1	Delta ASC_SM_E for group A1	utils	0.836	0.307	2.73
ASC_SM_E_A2	Delta ASC_SM_E for group A2	utils	0.655	0.278	2.36
ASC_SM	Base ASC_SM: When Age is 65 or more	utils	-2.320	0.205	-11.30
ASC_SM_A1	Delta ASC_SM for group A1	utils	1.290	0.233	5.54
ASC_SM_A2	Delta ASC_SM for group A2	utils	0.957	0.217	4.42
ASC_BIKE	Base ASC_BIKE: When Age is 65 or more	utils	-0.710	0.151	-4.70
ASC_BIKE_A1	Delta ASC_BIKE for group A1	utils	0.661	0.155	4.26
ASC_BIKE_A2	Delta ASC_BIKE for group A2	utils	0.424	0.137	3.11
Cost parameters			*Rho-square*		*0.176*
B_MAIN_COST	Base B_MAIN_COST: When Age is 55 or more	utils/€	-0.065	0.015	-4.36
B_MAIN_COST_A1	Delta B_MAIN_COST for group A1	utils/€	-0.046	0.016	-2.89
B_MAIN_COST_A2	Delta B_MAIN_COST for group A2	utils/€	-0.031	0.014	-2.29
B_EGRESS_COST	Base B_EGRESS_COST: When Age is 55 or more	utils/€	-0.131	0.083	-1.58
B_EGRESS_COST_A1	Delta B_EGRESS_COST for group A1	utils/€	-0.502	0.057	-8.74
B_EGRESS_COST_A2	Delta B_EGRESS_COST for group A2	utils/€	-0.381	0.046	-8.24
Time parameters			*Rho-square*		*0.182*
B_EGRESS_TIME	Base B_EGRESS_TIME: When Age is 55 or more	utils/min	0.043	0.016	2.75
B_EGRESS_TIME_A1	Delta B_EGRESS_TIME for group A1	utils/min	-0.146	0.018	-8.29
B_EGRESS_TIME_A2	Delta B_EGRESS_TIME for group A2	utils/min	-0.102	0.015	-6.96
B_MAIN_TIME	Base B_MAIN_TIME: When Age is 55 or more	utils/min	-0.020	0.009	-2.08
B_MAIN_TIME_A1	Delta B_MAIN_TIME for group A1	utils/min	-0.028	0.012	-2.41
B_MAIN_TIME_A2	Delta B_MAIN_TIME for group A2	utils/min	-0.014	0.010	-1.39
B_WALK	Base B_WALK: When Age is 55 or more	utils/min	-0.009	0.013	-0.72
B_WALK_A1	Delta B_WALK for group A1	utils/min	-0.093	0.014	-6.80
B_WALK_A2	Delta B_WALK for group A2	utils/min	-0.064	0.012	-5.51
B_METRO_WAIT	Base B_METRO_WAIT: When Age is 55 or more	utils/min	-0.056	0.044	-1.29
B_METRO_WAIT_A1	Delta B_METRO_WAIT for group A1	utils/min	0.064	0.054	1.19
B_METRO_WAIT_A2	Delta B_METRO_WAIT for group A2	utils/min	0.044	0.048	0.93

Legend: highlighted green: significant at 95% confidence interval; highlighted blue: significant at 99% confidence interval

Frequency of Public transport use

Categories	**Base**	**PT1**	**PT2**
3	< 1 time a week	1-4 times a week	>= 5 times a week

INTERACTIONS	*PT-Use*				
Name	Description	Unit	Value	Rob. SE	Rob. t-test
Alternative specific constants				*Rho-square*	*0.183*
ASC_METRO	Base ASC_METRO	utils	-1.420	0.205	-6.91
ASC_METRO_PT1	Delta ASC_METRO for group PT1	utils	1.270	0.132	9.57
ASC_METRO_PT2	Delta ASC_METRO for group PT2	utils	0.882	0.264	3.34
ASC_BT	Base ASC_BT	utils	0.697	0.243	2.87
ASC_BT_PT1	Delta ASC_BT for group PT1	utils	-0.186	0.116	-1.60
ASC_BT_PT2	Delta ASC_BT for group PT2	utils	0.720	0.179	4.02
ASC_SB	Base ASC_SB	utils	-0.894	0.276	-3.24
ASC_SB_PT1	Delta ASC_SB for group PT1	utils	-0.263	0.195	-1.35
ASC_SB_PT2	Delta ASC_SB for group PT2	utils	0.978	0.245	3.99
ASC_SM_E	Base ASC_SM_E	utils	-1.130	0.297	-3.81
ASC_SM_E_PT1	Delta ASC_SM_E for group PT1	utils	0.188	0.218	0.86
ASC_SM_E_PT2	Delta ASC_SM_E for group PT2	utils	0.711	0.340	2.09
ASC_SM	Base ASC_SM	utils	-1.740	0.103	-16.90
ASC_SM_PT1	Delta ASC_SM for group PT1	utils	0.839	0.139	6.02
ASC_SM_PT2	Delta ASC_SM for group PT2	utils	0.864	0.283	3.06
ASC_BIKE	Base ASC_BIKE	utils	-0.479	0.120	-3.98
ASC_BIKE_PT1	Delta ASC_BIKE for group PT1	utils	0.498	0.110	4.53
ASC_BIKE_PT2	Delta ASC_BIKE for group PT2	utils	0.383	0.250	1.53
Cost parameters				*Rho-square*	*0.176*
B_MAIN_COST	Base B_MAIN_COST	utils/€	-0.081	0.012	-6.91
B_MAIN_COST_PT1	Delta B_MAIN_COST for group PT1	utils/€	-0.043	0.011	-3.81
B_MAIN_COST_PT2	Delta B_MAIN_COST for group PT2	utils/€	-0.003	0.023	-0.12
B_EGRESS_COST	Base B_EGRESS_COST	utils/€	-0.668	0.087	-7.70
B_EGRESS_COST_PT	Delta B_EGRESS_COST for group PT1	utils/€	0.268	0.044	6.13
B_EGRESS_COST_PT	Delta B_EGRESS_COST for group PT2	utils/€	0.599	0.063	9.46
Time parameters				*Rho-square*	*0.178*
B_EGRESS_TIME	Base B_EGRESS_TIME	utils/min	-0.048	0.015	-3.28
B_EGRESS_TIME_PT	Delta B_EGRESS_TIME for group PT1	utils/min	-0.002	0.013	-0.19
B_EGRESS_TIME_PT	Delta B_EGRESS_TIME for group PT2	utils/min	0.044	0.020	2.23
B_MAIN_TIME	Base B_MAIN_TIME	utils/min	-0.019	0.007	-2.83
B_MAIN_TIME_PT1	Delta B_MAIN_TIME for group PT1	utils/min	-0.027	0.008	-3.35
B_MAIN_TIME_PT2	Delta B_MAIN_TIME for group PT2	utils/min	-0.037	0.015	-2.47
B_WALK	Base B_WALK	utils/min	-0.064	0.012	-5.51
B_WALK_PT1	Delta B_WALK for group PT1	utils/min	0.003	0.010	0.32
B_WALK_PT2	Delta B_WALK for group PT2	utils/min	-0.020	0.017	-1.15
B_METRO_WAIT	Base B_METRO_WAIT	utils/min	-0.074	0.031	-2.38
B_METRO_WAIT_PT	Delta B_METRO_WAIT for group PT1	utils/min	0.111	0.038	2.92
B_METRO_WAIT_PT	Delta B_METRO_WAIT for group PT2	utils/min	0.098	0.064	1.53

Legend: highlighted green: significant at 95% confidence interval; highlighted blue: significant at 99% confidence interval

Familiarity with shared modes

INTERACTIONS	*Familiarity with shared modes*				
Name	Description	Unit	Value	Rob. SE	Rob. t-test
Alternative specific constants				*Rho-square*	*0.172*
ASC_METRO	Base ASC_METRO	utils	-0.851	0.196	-4.350
ASC_BT	Base ASC_BT	utils	0.687	0.233	2.950
ASC_SB	Base ASC_SB	utils	-0.986	0.280	-3.52
ASC_SB_F	Delta ASC_SB for people familiar with shared mode	utils	0.187	0.188	0.99
ASC_SM_E	Base ASC_SM_E	utils	-1.300	0.326	-3.98
ASC_SM_E_F	Delta ASC_SM_E for people familiar with shared m	utils	0.439	0.236	1.86
ASC_SM	Base ASC_SM	utils	-2.110	0.163	-12.90
ASC_SM_F	Delta ASC_SM for people familiar with shared mod	utils	0.856	0.164	5.20
ASC_BIKE	Base ASC_BIKE	utils	-0.274	0.108	-2.550
Cost parameters				*Rho-square*	*0.172*
B_EGRESS_COST	Base B_EGRESS_COST	utils/€	-0.259	0.084	-3.07
B_EGRESS_COST_F	Delta B_EGRESS_COST for people familiar with sha	utils/€	-0.246	0.044	-5.58
B_MAIN_COST	Base B_MAIN_COST	utils/€	-0.066	0.015	-4.33
B_MAIN_COST_F	Delta B_MAIN_COST for people familiar with share	utils/€	-0.035	0.014	-2.56

Legend: highlighted green: significant at 95% confidence interval; highlighted blue: significant at 99% confidence interval

Previous use of shared modes

INTERACTIONS	*Having used shared modes previously*				
Name	Description	Unit	Value	Rob. SE	Rob. t-test
Alternative specific constants				*Rho-square*	*0.177*
ASC_METRO	Base ASC_METRO	utils	-0.866	0.196	-4.42
ASC_BT	Base ASC_BT	utils	0.684	0.232	2.95
ASC_SB	Base ASC_SB	utils	-0.993	0.248	-4.00
ASC_SB_U	Delta ASC_SB if having used shared modes before	utils	0.659	0.167	3.94
ASC_SM_E	Base ASC_SM_E	utils	-1.200	0.265	-4.55
ASC_SM_E_U	Delta ASC_SM_E if having used shared modes befo	utils	1.080	0.185	5.82
ASC_SM	Base ASC_SM	utils	-1.690	0.091	-18.50
ASC_SM_U	Delta ASC_SM if having used shared modes before	utils	1.150	0.119	9.68
ASC_BT	Base ASC_BT	utils	0.684	0.232	2.95
Cost parameters				*Rho-square*	*0.17*
B_EGRESS_COST	Base B_EGRESS_COST	utils/€	-0.411	0.080	-5.17
B_EGRESS_COST_U	Delta B_EGRESS_COST for people familiar with sha	utils/€	-0.246	0.052	-1.57
B_MAIN_COST	Base B_MAIN_COST	utils/€	-0.066	0.011	-7.97
B_MAIN_COST_U	Delta B_MAIN_COST for people familiar with share	utils/€	-0.035	0.012	-2.07

Legend: highlighted green: significant at 95% confidence interval; highlighted blue: significant at 99% confidence interval

Gross annual income

Categories	Base	I1	I2
3	< €30.000	€30.000 - €50.000	> €50.000

INTERACTIONS	*Income*				
Name	Description	Unit	Value	Rob. SE	Rob. t-test
Alternative specific constants				*Rho-square*	*0.164*
ASC_METRO	Base ASC_METRO	utils	-0.687	0.238	-2.89
ASC_METRO_I1	Delta ASC_METRO for group I1	utils	-0.307	0.160	-1.92
ASC_METRO_I2	Delta ASC_METRO for group I2	utils	0.163	0.166	0.98
ASC_BT	Base ASC_BT	utils	0.664	0.269	2.47
ASC_BT_I1	Delta ASC_BT for group I1	utils	-0.023	0.139	-0.17
ASC_BT_I2	Delta ASC_BT for group I2	utils	-0.683	0.157	-4.34
ASC_SB	Base ASC_SB	utils	-0.773	0.290	-2.67
ASC_SB_I1	Delta ASC_SB for group I1	utils	-0.252	0.216	-1.16
ASC_SB_I2	Delta ASC_SB for group I2	utils	-0.536	0.232	-2.31
ASC_SM_E	Base ASC_SM_E	utils	-0.815	0.308	-2.65
ASC_SM_E_I1	Delta ASC_SM_E for group I1	utils	-0.286	0.245	-1.17
ASC_SM_E_I2	Delta ASC_SM_E for group I2	utils	-0.525	0.258	-2.03
ASC_SM	Base ASC_SM	utils	-1.310	0.137	-9.61
ASC_SM_I1	Delta ASC_SM for group I1	utils	-0.141	0.169	-0.83
ASC_SM_I2	Delta ASC_SM for group I2	utils	0.341	0.173	1.97
ASC_BIKE	Base ASC_BIKE	utils	-0.357	0.149	-2.40
ASC_BIKE_I1	Delta ASC_BIKE for group I1	utils	-0.156	0.138	-1.14
ASC_BIKE_I2	Delta ASC_BIKE for group I2	utils	0.238	0.139	1.71
Cost parameters				*Rho-square*	*0.162*
B_MAIN_COST	Base B_MAIN_COST	utils/€	-0.114	0.015	-7.48
B_MAIN_COST_I1	Delta B_MAIN_COST for group I1	utils/€	0.036	0.015	2.45
B_MAIN_COST_I2	Delta B_MAIN_COST for group I2	utils/€	0.004	0.015	0.28
B_EGRESS_COST	Base B_EGRESS_COST	utils/€	-0.279	0.091	-3.08
B_EGRESS_COST_I1	Delta B_EGRESS_COST for group I1	utils/€	-0.128	0.051	-2.53
B_EGRESS_COST_I2	Delta B_EGRESS_COST for group I2	utils/€	-0.348	0.060	-5.78
Time parameters				*Rho-square*	*0.162*
B_EGRESS_TIME	Base B_EGRESS_TIME	utils/min	-0.024	0.015	-1.60
B_EGRESS_TIME_I1	Delta B_EGRESS_TIME for group I1	utils/min	-0.008	0.015	-0.50
B_EGRESS_TIME_I2	Delta B_EGRESS_TIME for group I2	utils/min	-0.063	0.017	-3.67
B_MAIN_TIME	Base B_MAIN_TIME	utils/min	-0.035	0.008	-4.48
B_MAIN_TIME_I1	Delta B_MAIN_TIME for group I1	utils/min	0.008	0.010	0.80
B_MAIN_TIME_I2	Delta B_MAIN_TIME for group I2	utils/min	-0.004	0.011	-0.34
B_METRO_WAIT	Base B_METRO_WAIT	utils/min	-0.003	0.035	-0.08
B_METRO_WAIT_I1	Delta B_METRO_WAIT for group I1	utils/min	-0.025	0.046	-0.54
B_METRO_WAIT_I2	Delta B_METRO_WAIT for group I2	utils/min	0.011	0.048	0.24

Legend: highlighted green: significant at 95% confidence interval; highlighted blue: significant at 99% confidence interval

Highest completed level of education

Categories	Base	E1	E2
3	Below 1	MBO - HAVO/VWO	HBO/WO, bachelor or higher

INTERACTIONS	*Education*				
Name	Description	Unit	Value	Rob. SE	Rob. t-test
Alternative specific constants				*Rho-square*	*0.177*
ASC_METRO	Base ASC_METRO	utils	-0.836	0.247	-3.38
ASC_METRO_E1	Delta ASC_METRO for group E1	utils	-0.388	0.186	-2.08
ASC_METRO_E2	Delta ASC_METRO for group E2	utils	0.342	0.187	1.83
ASC_BT	Base ASC_BT	utils	1.140	0.261	4.37
ASC_BT_E1	Delta ASC_BT for group E1	utils	-0.182	0.145	-1.26
ASC_BT_E2	Delta ASC_BT for group E2	utils	-0.907	0.153	-5.93
ASC_SB	Base ASC_SB	utils	-0.773	0.307	-2.52
ASC_SB_E1	Delta ASC_SB for group E1	utils	0.204	0.245	0.84
ASC_SB_E2	Delta ASC_SB for group E2	utils	-0.223	0.254	-0.88
ASC_SM_E	Base ASC_SM_E	utils	-1.090	0.383	-2.84
ASC_SM_E_E1	Delta ASC_SM_E for group E1	utils	0.548	0.321	1.71
ASC_SM_E_E2	Delta ASC_SM_E for group E2	utils	0.016	0.327	0.05
ASC_SM	Base ASC_SM	utils	-2.030	0.230	-8.80
ASC_SM_E1	Delta ASC_SM for group E1	utils	0.016	0.327	0.05
ASC_SM_E2	Delta ASC_SM for group E2	utils	0.016	0.327	0.05
ASC_BIKE	Base ASC_BIKE	utils	-0.555	0.175	-3.17
ASC_BIKE_E1	Delta ASC_BIKE for group E1	utils	0.028	0.167	0.17
ASC_BIKE_E2	Delta ASC_BIKE for group E2	utils	0.638	0.166	3.84
Cost parameters				*Rho-square*	*0.174*
B_MAIN_COST	Base B_MAIN_COST	utils/€	-0.068	0.018	-3.78
B_MAIN_COST_E1	Delta B_MAIN_COST for group E1	utils/€	-0.004	0.017	-0.23
B_MAIN_COST_E2	Delta B_MAIN_COST for group E2	utils/€	-0.061	0.017	-3.50
B_EGRESS_COST	Base B_EGRESS_COST	utils/€	-0.189	0.089	-2.11
B_EGRESS_COST_E1	Delta B_EGRESS_COST for group E1	utils/€	-0.234	0.053	-4.40
B_EGRESS_COST_E2	Delta B_EGRESS_COST for group E2	utils/€	-0.451	0.058	-7.78
Time parameters				*Rho-square*	*0.174*
B_EGRESS_TIME	Base B_EGRESS_TIME	utils/min	0.016	0.018	0.90
B_EGRESS_TIME_E1	Delta B_EGRESS_TIME for group E1	utils/min	-0.049	0.017	-2.89
B_EGRESS_TIME_E2	Delta B_EGRESS_TIME for group E2	utils/min	-0.114	0.018	-6.32
B_MAIN_TIME	Base B_MAIN_TIME	utils/min	-0.032	0.011	-2.89
B_MAIN_TIME_E1	Delta B_MAIN_TIME for group E1	utils/min	0.004	0.012	0.37
B_MAIN_TIME_E2	Delta B_MAIN_TIME for group E2	utils/min	-0.011	0.012	-0.94
B_WALK	Base B_WALK	utils/min	-0.030	0.015	-1.94
B_WALK_E1	Delta B_WALK for group E1	utils/min	-0.035	0.014	-2.44
B_WALK_E2	Delta B_WALK for group E2	utils/min	-0.046	0.014	-3.23
B_METRO_WAIT	Base B_METRO_WAIT	utils/min	-0.070	0.051	-1.37
B_METRO_WAIT_E1	Delta B_METRO_WAIT for group E1	utils/min	0.041	0.056	0.72
B_METRO_WAIT_E2	Delta B_METRO_WAIT for group E2	utils/min	0.102	0.057	1.81

Legend: highlighted green: significant at 95% confidence interval; highlighted blue: significant at 99% confidence interval

C. Mixed logit (ML) model

C.1 Biogeme syntax – Nesting effects

ML to capture nesting effects (No panel)

Example of ML model to capture nesting effects without considering panel effects. Other nests are modelled analogously.

```
# ML Model for the whole trip using numerical integration
# Nest of bike alternatives
# No panel effects

import pandas as pd
import biogeme.database as db
import biogeme.distributions as dist
import biogeme.biogeme as bio
from biogeme import models
import biogeme.messaging as msg
from biogeme.expressions import (Beta, Integrate,
DefineVariable, RandomVariable, exp, bioDraws,
PanelLikelihoodTrajectory, MonteCarlo, log)

df = pd.read_csv('data.csv', skipinitialspace=True,
index_col=0)
database = db.Database('data', df)  # create database for
biogeme

globals().update(database.variables) # define headers of
columns as variables

# Exclude cases in which either or B was not answered
exclude = ((A == 0) + (B == 0)) >= 1
database.remove(exclude)

# Parameters to be estimated
# Alternative specific constants
ASC_METRO = Beta('ASC_METRO', 0, None, None, 0)
ASC_BT = Beta('ASC_BT', 0, None, None, 0)
ASC_SB = Beta('ASC_SB', 0, None, None, 0)
ASC_SM_E = Beta('ASC_SM_E', 0, None, None, 0)
ASC_SM = Beta('ASC_SM', 0, None, None, 0)
ASC_BIKE = Beta('ASC_BIKE', 0, None, None, 0)
ASC_CAR = Beta('ASC_CAR', 0, None, None, 1)

SIGMA_BIKE = Beta('SIGMA_BIKE', 1, None, None, 0)
omega = RandomVariable('omega')
density = dist.normalpdf(omega)
SIGMA_BIKE_RND = SIGMA_BIKE * omega

# Parameters to be estimated
# Betas
# Main
B_METRO_WAIT = Beta('B_METRO_WAIT', 0, None, None,
0)
B_MAIN_TIME = Beta('B_MAIN_TIME', 0, None, None, 0)
B_MAIN_COST = Beta('B_MAIN_COST', 0, None, None, 0)

# Egress
B_EGRESS_TIME = Beta('B_EGRESS_TIME', 0, None, None,
0)
B_WALK = Beta('B_WALK', 0, None, None, 0)
B_EGRESS_COST = Beta('B_EGRESS_COST', 0, None, None,
0)

# New variables for availability of alternatives
metro_bt = 1
metro_sb = SharedBike
metro_sm = SharedMoped
metro_walk = 1

# Specificacion of utility functions
# Metro alternatives
V1 = ASC_METRO + ASC_BT + B_METRO_WAIT*metro_wt +
B_MAIN_TIME*metro_vt + B_MAIN_COST*metro_cost +
B_EGRESS_TIME*(bt_vt + bt_wt) + B_WALK*bt_walk +
B_EGRESS_COST*bt_cost # Metro & BT

V2 = ASC_METRO + ASC_SB + SIGMA_BIKE_RND +
B_METRO_WAIT*metro_wt + B_MAIN_TIME*metro_vt +
B_MAIN_COST*metro_cost + B_EGRESS_TIME*sbike_vt +
B_EGRESS_COST*sbike_cost # Metro & Shared Bike

V3 = ASC_METRO + ASC_SM_E +
B_METRO_WAIT*metro_wt + B_MAIN_TIME*metro_vt +
B_MAIN_COST*metro_cost + B_EGRESS_TIME*smoped_vt
+ B_EGRESS_COST*smoped_cost # Metro & Shared Bike

V4 = ASC_METRO + B_METRO_WAIT*metro_wt +
B_MAIN_TIME*metro_vt + B_MAIN_COST*metro_cost +
B_WALK*walk_t

# Other alternatives
V5 = ASC_SM + B_WALK*smoped2_search +
B_MAIN_TIME*smoped2_vt +
B_MAIN_COST*smoped2_cost
V6 = ASC_CAR + B_MAIN_TIME*car_vt + B_WALK*car_walk
+ B_MAIN_COST*(car_cost + car_park)
```

```
V7 = ASC_BIKE + SIGMA_BIKE_RND +
B_MAIN_TIME*bike_vt

# Associating utility functions with alternatives
V = {1: V1,
    2: V2,
    3: V3,
    4: V4,
    5: V5,
    6: V6,
    7: V7}

# Availability of alternatives
av = {1: metro_bt,
     2: metro_sb,
     3: metro_sm,
     4: metro_walk,
     5: SharedMoped,
     6: Car,
     7: Bike}

# Defining choice model and creating BIOGEME object
condprob = models.logit(V, av, B)
logprob = log(Integrate(condprob*density, 'omega'))
logger = msg.bioMessage()
logger.setGeneral()
biogeme = bio.BIOGEME(database, logprob)
biogeme.modelName = 'ML_NestingInt_Bike'
results = biogeme.estimate()
```

ML to capture nesting effects

Example of ML model including panel effects to capture nest of alternatives. Other nests are modelled analogously.

```
# ML Model for the whole trip
# Nest of bike alternatives
# Panel effects

import pandas as pd
import biogeme.database as db
import biogeme.biogeme as bio
from biogeme import models
import biogeme.messaging as msg
from biogeme.expressions import (Beta, Integrate,
DefineVariable, RandomVariable, exp, bioDraws,
PanelLikelihoodTrajectory, MonteCarlo, log)

df = pd.read_csv('data.csv', skipinitialspace=True,
index_col=0)  # read data
database = db.Database('data', df)  # create database for
biogeme

database.panel("ID")

globals().update(database.variables) # define columns as
variables

# Exclude cases in which either or B was not answered
exclude = ((A == 0) + (B == 0)) >= 1
database.remove(exclude)

# Parameters to be estimated
# Alternative specific constants
ASC_METRO = Beta('ASC_METRO', 0, None, None, 0)
ASC_BT = Beta('ASC_BT', 0, None, None, 0)
ASC_SB = Beta('ASC_SB', 0, None, None, 0)
ASC_SM_E = Beta('ASC_SM_E', 0, None, None, 0)
ASC_SM = Beta('ASC_SM', 0, None, None, 0)
ASC_BIKE = Beta('ASC_BIKE', 0, None, None, 0)
ASC_CAR = Beta('ASC_CAR', 0, None, None, 1)

SIGMA_BIKE = Beta('SIGMA_BIKE', 1, None, None, 0)
SIGMA_BIKE_RND = SIGMA_BIKE *
bioDraws('SIGMA_BIKE_RND', 'NORMAL')

# Parameters to be estimated
# Betas
# Main
B_METRO_WAIT = Beta('B_METRO_WAIT', 0, None, None,
0)
B_MAIN_TIME = Beta('B_MAIN_TIME', 0, None, None, 0)
B_MAIN_COST = Beta('B_MAIN_COST', 0, None, None, 0)

# Egress
B_EGRESS_TIME = Beta('B_EGRESS_TIME', 0, None, None,
0)
B_WALK = Beta('B_WALK', 0, None, None, 0)
B_EGRESS_COST = Beta('B_EGRESS_COST', 0, None, None,
0)

# New variables for availability of alternatives
metro_bt = 1
metro_sb = SharedBike
metro_sm = SharedMoped
metro_walk = 1

# Specificacion of utility functions
# Metro alternatives
V1 = ASC_METRO + ASC_BT + B_METRO_WAIT*metro_wt +
B_MAIN_TIME*metro_vt + B_MAIN_COST*metro_cost +
B_EGRESS_TIME*(bt_vt + bt_wt) + B_WALK*bt_walk +
B_EGRESS_COST*bt_cost # Metro & BT
V2 = ASC_METRO + ASC_SB + SIGMA_BIKE_RND +
B_METRO_WAIT*metro_wt + B_MAIN_TIME*metro_vt +
B_MAIN_COST*metro_cost + B_EGRESS_TIME*sbike_vt +
B_EGRESS_COST*sbike_cost # Metro & Shared Bike
V3 = ASC_METRO + ASC_SM_E +
B_METRO_WAIT*metro_wt + B_MAIN_TIME*metro_vt +
B_MAIN_COST*metro_cost + B_EGRESS_TIME*smoped_vt
+ B_EGRESS_COST*smoped_cost # Metro & Shared Bike
```

```
V4 = ASC_METRO + B_METRO_WAIT*metro_wt +
B_MAIN_TIME*metro_vt + B_MAIN_COST*metro_cost +
B_WALK*walk_t

# Other alternatives
V5 = ASC_SM + B_WALK*smoped2_search +
B_MAIN_TIME*smoped2_vt +
B_MAIN_COST*smoped2_cost
V6 = ASC_CAR + B_MAIN_TIME*car_vt + B_WALK*car_walk
+ B_MAIN_COST*(car_cost + car_park)
V7 = ASC_BIKE + SIGMA_BIKE_RND +
B_MAIN_TIME*bike_vt

# Associating utility functions with alternatives
V = {1: V1,
   2: V2,
   3: V3,
   4: V4,
   5: V5,
   6: V6,
   7: V7}

# Availability of alternatives
av = {1: metro_bt,
    2: metro_sb,
    3: metro_sm,
    4: metro_walk,
    5: SharedMoped,
    6: Car,
    7: Bike}

# Defining choice model and creating BIOGEME object
obsprob = models.logit(V, av, B)
condprobIndiv = PanelLikelihoodTrajectory(obsprob)
logprob = log(MonteCarlo(condprobIndiv))
logger = msg.bioMessage()
logger.setDetailed()
biogeme = bio.BIOGEME(database, logprob,
numberOfDraws = 250)
biogeme.modelName = 'ML_Nesting&Panel_Bike'
results = biogeme.estimate()
```

ML to capture nesting effects: Cross-nesting

Example of ML model including panel effects to capture nest of alternatives. All nests are included to account for cross-nesting

```
# ML Model for the whole trip - Cross-nesting
# Panel effects
import pandas as pd
import biogeme.database as db
import biogeme.biogeme as bio
from biogeme import models
import biogeme.messaging as msg
from biogeme.expressions import (Beta, Integrate,
DefineVariable, RandomVariable, exp, bioDraws,
PanelLikelihoodTrajectory, MonteCarlo, log)

df = pd.read_csv('data.csv', skipinitialspace=True,
index_col=0)  # read data
database = db.Database('data', df)  # create database for
biogeme

database.panel("ID")

globals().update(database.variables) # define headers of
columns as variables

# Exclude cases in which either or B was not answered
exclude = ((A == 0) + (B == 0)) >= 1
database.remove(exclude)

# Parameters to be estimated
# Alternative specific constants
ASC_METRO = Beta('ASC_METRO', 0, None, None, 0)
SIGMA_METRO = Beta('SIGMA_METRO', 1, None, None, 0)
ASC_METRO_RND = ASC_METRO + SIGMA_METRO *
bioDraws('ASC_METRO_RND', 'NORMAL')
ASC_BT = Beta('ASC_BT', 0, None, None, 0)
ASC_SB = Beta('ASC_SB', 0, None, None, 0)
ASC_SM_E = Beta('ASC_SM_E', 0, None, None, 0)
ASC_SM = Beta('ASC_SM', 0, None, None, 0)
ASC_BIKE = Beta('ASC_BIKE', 0, None, None, 0)
ASC_CAR = Beta('ASC_CAR', 0, None, None, 1)

# Parameters to be estimated
# Main
B_MAIN_TIME = Beta('B_MAIN_TIME', 0, None, None, 0)
B_MAIN_COST = Beta('B_MAIN_COST', 0, None, None, 0)

# Egress
B_EGRESS_TIME = Beta('B_EGRESS_TIME', 0, None, None,
0)
B_WALK = Beta('B_WALK', 0, None, None, 0)
B_EGRESS_COST = Beta('B_EGRESS_COST', 0, None, None,
0)

#Nests
SIGMA_PRIVATE = Beta('SIGMA_PRIVATE', 1, None, None,
0)
SIGMA_PRIVATE_RND =
SIGMA_PRIVATE*bioDraws('SIGMA_PRIVATE_RND',
'NORMAL')

SIGMA_B = Beta('SIGMA_B', 1, None, None, 0)
SIGMA_B_RND = SIGMA_B*bioDraws('SIGMA_B_RND',
'NORMAL')

SIGMA_SHARED_E = Beta('SIGMA_SHARED_E', 1, None,
None, 0)
```

```
SIGMA_SHARED_E_RND =
SIGMA_SHARED_E*bioDraws('SIGMA_SHARED_E_RND',
'NORMAL')

SIGMA_MOPED = Beta('SIGMA_MOPED', 1, None, None, 0)
SIGMA_MOPED_RND =
SIGMA_MOPED*bioDraws('SIGMA_MOPED_RND',
'NORMAL')

# New variables for availability of alternatives
metro_bt = 1
metro_sb = SharedBike
metro_sm = SharedMoped
metro_walk = 1

# Specificacion of utility functions
# Metro alternatives
V1 = ASC_METRO_RND + ASC_BT +
B_MAIN_TIME*metro_vt + B_MAIN_COST*metro_cost +
B_EGRESS_TIME*(bt_vt + bt_wt) + B_WALK*bt_walk +
B_EGRESS_COST*bt_cost
V2 = ASC_METRO_RND + ASC_SB + SIGMA_B_RND +
SIGMA_SHARED_E_RND + B_MAIN_TIME*metro_vt +
B_MAIN_COST*metro_cost + B_EGRESS_TIME*sbike_vt +
B_EGRESS_COST*sbike_cost
V3 = ASC_METRO_RND + ASC_SM_E +
SIGMA_SHARED_E_RND + SIGMA_MOPED_RND +
B_MAIN_TIME*metro_vt + B_MAIN_COST*metro_cost +
B_EGRESS_TIME*smoped_vt +
B_EGRESS_COST*smoped_cost
V4 = ASC_METRO_RND + B_MAIN_TIME*metro_vt +
B_MAIN_COST*metro_cost + B_WALK*walk_t

# Other alternatives
V5 = ASC_SM + SIGMA_MOPED_RND +
B_WALK*smoped2_search + B_MAIN_TIME*smoped2_vt +
B_MAIN_COST*smoped2_cost
V6 = ASC_CAR + SIGMA_PRIVATE_RND +
B_MAIN_TIME*car_vt + B_WALK*car_walk +
B_MAIN_COST*(car_cost + car_park)
V7 = ASC_BIKE + SIGMA_PRIVATE_RND + SIGMA_B_RND +
B_MAIN_TIME*bike_vt

# Associating utility functions with alternatives
V = {1: V1,
    2: V2,
    3: V3,
    4: V4,
    5: V5,
    6: V6,
    7: V7}

# Availability of alternatives
av = {1: metro_bt,
     2: metro_sb,
     3: metro_sm,
     4: metro_walk,
     5: SharedMoped,
     6: Car,
     7: Bike}

# Defining choice model and creating BIOGEME object
obsprob = models.logit(V, av, B)
condprobIndiv = PanelLikelihoodTrajectory(obsprob)
logprob = log(MonteCarlo(condprobIndiv))
logger = msg.bioMessage()
logger.setGeneral()
biogeme = bio.BIOGEME(database, logprob,
numberOfDraws = 2000)
biogeme.modelName = 'ML_CrossNesting'
results = biogeme.estimate()
```

C.2 Results – Nesting effects

BIKE MODES: Bike and Metro/shared bike								
			Only Nest				*Nest and Panel*	
			Rho-square	**0.166**			*Rho-square*	*0.266*
Name	**Value**	**Rob. SE**	**Rob. t-test**	**Rob. p-value**	*Value*	*Rob. SE*	*Rob. t-test*	*Rob. p-value*
ASC_BIKE	-0.302	0.112	-2.7	0.00695	*-0.527*	*0.191*	*-2.75*	*0.00592*
ASC_BT	0.697	0.234	2.98	0.00289	*0.889*	*0.245*	*3.63*	*0.000285*
ASC_METRO	-0.896	0.201	-4.46	0.00000809	*-1.07*	*0.222*	*-4.82*	*0.00000147*
ASC_SB	-0.885	0.246	-3.59	0.000331	*-0.979*	*0.3*	*-3.27*	*0.00108*
ASC_SM	-1.4	0.083	-16.9	0	*-1.49*	*0.125*	*-11.9*	*0*
ASC_SM_E	-0.915	0.26	-3.51	0.000441	*-0.743*	*0.294*	*-2.52*	*0.0116*
B_EGRESS_COST	-0.433	0.08	-5.41	6.14E-08	*-0.49*	*0.0773*	*-6.34*	*2.26E-10*
B_EGRESS_TIME	-0.0395	0.0121	-3.27	0.00106	*-0.047*	*0.0107*	*-4.39*	*0.0000115*
B_MAIN_COST	-0.0955	0.0111	-8.57	0	*-0.105*	*0.0114*	*-9.27*	*0*
B_MAIN_TIME	-0.0346	0.00525	-6.59	4.32E-11	*-0.0444*	*0.00514*	*-8.65*	*0*
B_METRO_WAIT	-0.0124	0.0229	-0.539	0.59	*-0.00947*	*0.02*	*-0.474*	*0.635*
B_WALK	-0.0638	0.0102	-6.26	3.76E-10	*-0.0635*	*0.0089*	*-7.14*	*9.47E-13*
SIGMA_BIKE	0.591	0.253	2.34	0.0193	*2.95*	*0.182*	*16.2*	*0*

Legend: highlighted green: significant at 95% confidence interval; highlighted blue: significant at 99% confidence interval

METRO MODES: All metro/egress combinations								
			Only Nest				*Nest and Panel*	
			Rho-square	**0.161**			*Rho-square*	*0.265*
Name	**Value**	**Rob. SE**	**Rob. t-test**	**Rob. p-value**	*Value*	*Rob. SE*	*Rob. t-test*	*Rob. p-value*
ASC_BIKE	-0.303	0.113	-2.69	0.00712	*-0.462*	*0.144*	*-3.21*	*0.00133*
ASC_BT	0.647	0.237	2.73	0.00634	*0.571*	*0.239*	*2.39*	*0.0168*
ASC_METRO	-0.886	0.2	-4.42	0.00000982	*-1.4*	*0.261*	*-5.38*	*7.58E-08*
ASC_SB	-0.91	0.252	-3.6	0.000314	*-1.04*	*0.276*	*-3.76*	*0.000171*
ASC_SM	-1.42	0.0888	-16	0	*-1.58*	*0.127*	*-12.4*	*0*
ASC_SM_E	-0.984	0.266	-3.71	0.00021	*-1.11*	*0.297*	*-3.72*	*0.000196*
B_EGRESS_COST	-0.432	0.0797	-5.42	5.91E-08	*-0.453*	*0.0725*	*-6.25*	*4.04E-10*
B_EGRESS_TIME	-0.0399	0.0121	-3.29	0.00102	*-0.046*	*0.0109*	*-4.2*	*0.0000262*
B_MAIN_COST	-0.0963	0.0113	-8.54	0	*-0.113*	*0.0116*	*-9.68*	*0*
B_MAIN_TIME	-0.0356	0.00558	-6.38	1.75E-10	*-0.0516*	*0.00586*	*-8.81*	*0*
B_METRO_WAIT	-0.0175	0.0242	-0.724	0.469	*-0.056*	*0.0297*	*-1.89*	*0.0594*
B_WALK	-0.0678	0.0114	-5.95	2.74E-09	*-0.0822*	*0.0103*	*-7.96*	*1.78E-15*
SIGMA_METRO	0.67	0.334	2	0.045	*2.78*	*0.166*	*16.8*	*0*

Legend: highlighted green: significant at 95% confidence interval; highlighted blue: significant at 99% confidence interval

PRIVATE MODES: Bike and Car								
	Only Nest				***Nest and Panel***			
			Rho-square	**0.148**			***Rho-square***	***0.267***
Name	**Value**	**Rob. SE**	**Rob. t-test**	**Rob. p-value**	***Value***	***Rob. SE***	***Rob. t-test***	***Rob. p-value***
ASC_BIKE	-0.284	0.112	-2.54	1.10E-02	*-0.428*	*0.151*	*-2.84*	*0.00457*
ASC_BT	0.667	0.234	2.85	4.39E-03	*0.649*	*0.234*	*2.77*	*0.00559*
ASC_METRO	-0.864	0.204	-4.24	2.19E-05	*-1.21*	*0.251*	*-4.83*	*0.00000138*
ASC_SB	-0.893	0.247	-3.62	2.94E-04	*-0.946*	*0.27*	*-3.51*	*0.000452*
ASC_SM	-1.42	0.0883	-16.1	0.00E+00	*-1.82*	*0.172*	*-10.5*	*0*
ASC_SM_E	-0.965	0.261	-3.7	2.12E-04	*-0.999*	*0.291*	*-3.43*	*0.000596*
B_EGRESS_COST	-0.434	0.0797	-5.44	5.33E-08	*-0.445*	*0.0719*	*-6.19*	*6.09E-10*
B_EGRESS_TIME	-0.0411	0.0123	-3.35	8.01E-04	*-0.0452*	*0.0108*	*-4.19*	*0.0000273*
B_MAIN_COST	-0.0966	0.0113	-8.57	0.00E+00	*-0.115*	*0.0124*	*-9.29*	*0*
B_MAIN_TIME	-0.0355	0.00546	-6.5	7.93E-11	*-0.0466*	*0.00547*	*-8.52*	*0*
B_METRO_WAIT	-0.0161	0.024	-0.67	5.03E-01	*-0.0398*	*0.0239*	*-1.66*	*0.0962*
B_WALK	-0.0676	0.0108	-6.25	4.20E-10	*-0.0741*	*0.00971*	*-7.64*	*2.26E-14*
SIGMA_PRIVATE	0.84	0.302	2.79	5.31E-03	*2.74*	*0.161*	*17*	*0*

Legend: highlighted green: significant at 95% confidence interval; highlighted blue: significant at 99% confidence interval

SHARED MODES AS EGRESS: Shared bike and shared moped as egress modes for metro								
	Only Nest				***Nest and Panel***			
			Rho-square	**0.177**			***Rho-square***	***0.190***
Name	**Value**	**Rob. SE**	**Rob. t-test**	**Rob. p-value**	***Value***	***Rob. SE***	***Rob. t-test***	***Rob. p-value***
ASC_BIKE	-0.273	0.108	-2.54	0.0112	*-0.274*	*0.131*	*-2.1*	*0.0358*
ASC_BT	0.673	0.235	2.87	0.00415	*0.785*	*0.239*	*3.29*	*0.00101*
ASC_METRO	-0.858	0.195	-4.39	0.0000113	*-0.852*	*0.196*	*-4.34*	*0.0000143*
ASC_SB	-0.966	0.462	-2.09	0.0363	*-2.15*	*0.33*	*-6.51*	*7.6E-11*
ASC_SM	-1.47	0.295	-4.96	0.0000007	*-1.39*	*0.117*	*-11.8*	*0*
ASC_SM_E	-1.02	0.411	-2.49	0.0127	*-2.02*	*0.342*	*-5.91*	*3.5E-09*
B_EGRESS_COST	-0.426	0.0798	-5.34	9.35E-08	*-0.472*	*0.0805*	*-5.87*	*4.43E-09*
B_EGRESS_TIME	-0.0386	0.0121	-3.18	0.00149	*-0.0406*	*0.0106*	*-3.82*	*0.000134*
B_MAIN_COST	-0.0933	0.0108	-8.66	0	*-0.0947*	*0.0103*	*-9.2*	*0*
B_MAIN_TIME	-0.0338	0.00512	-6.6	3.99E-11	*-0.0339*	*0.00408*	*-8.31*	*0*
B_METRO_WAIT	-0.0145	0.0223	-0.65	0.515	*-0.0172*	*0.0175*	*-0.984*	*0.325*
B_WALK	-0.0639	0.0102	-6.27	3.66E-10	*-0.0631*	*0.00848*	*-7.44*	*1.04E-13*
SIGMA_SHARED_E	0.544	1.01	0.541	0.589	*1.98*	*0.142*	*13.9*	*0*

Legend: highlighted green: significant at 95% confidence interval; highlighted blue: significant at 99% confidence interval

SHARED MOPED: Alternatives with shared moped included								
	Only Nest				*Nest and Panel*			
			Rho-square	**1.79E-01**			*Rho-square*	*0.210*
Name	**Value**	**Rob. SE**	**Rob. t-test**	**Rob. p-value**	*Value*	*Rob. SE*	*Rob. t-test*	*Rob. p-value*
ASC_BIKE	-0.274	0.107	-2.56	0.0104	*-0.285*	*0.133*	*-2.13*	*0.0328*
ASC_BT	0.673	0.234	2.88	0.00398	*0.69*	*0.235*	*2.94*	*0.00328*
ASC_METRO	-0.858	0.195	-4.4	0.0000109	*-0.876*	*0.203*	*-4.32*	*0.0000154*
ASC_SB	-0.867	0.245	-3.54	0.0004	*-0.843*	*0.269*	*-3.13*	*0.00173*
ASC_SM	-1.44	0.279	-5.16	0.000000253	*-2.76*	*0.207*	*-13.3*	*0*
ASC_SM_E	-0.997	0.398	-2.51	0.0122	*-2.29*	*0.345*	*-6.64*	*3.2E-11*
B_EGRESS_COST	-0.425	0.0793	-5.37	7.94E-08	*-0.441*	*0.073*	*-6.04*	*1.5E-09*
B_EGRESS_TIME	-0.0387	0.0121	-3.21	0.00134	*-0.039*	*0.0102*	*-3.82*	*0.000131*
B_MAIN_COST	-0.0933	0.0108	-8.67	0	*-0.0957*	*0.0105*	*-9.12*	*0*
B_MAIN_TIME	-0.0338	0.00516	-6.55	5.74E-11	*-0.0354*	*0.00419*	*-8.45*	*0*
B_METRO_WAIT	-0.0145	0.0223	-0.651	0.515	*-0.0134*	*0.0166*	*-0.81*	*0.418*
B_WALK	-0.0639	0.0102	-6.25	4.12E-10	*-0.065*	*0.00891*	*-7.3*	*2.9E-13*
SIGMA_MOPED	0.401	1.04	0.386	0.699	*2.39*	*0.16*	*14.9*	*0*

Legend: highlighted green: significant at 95% confidence interval; highlighted blue: significant at 99% confidence interval

C.3 Syntax – taste heterogeneity

ML to capture taste heterogeneity (No Panel)

Example of ML model to capture taste heterogeneity for one parameter without considering panel effects. All other random parameters are modelled analogously.

```
# ML Model using numerical integration
# Taste heterogeneity: B_EGRESS_COST
# No panel effects

import pandas as pd
import biogeme.database as db
import biogeme.biogeme as bio
import biogeme.distributions as dist
from biogeme import models
import biogeme.messaging as msg
from biogeme.expressions import (Beta, Integrate,
DefineVariable, RandomVariable, exp, bioDraws,
PanelLikelihoodTrajectory, MonteCarlo, log)

df = pd.read_csv('data.csv', skipinitialspace=True,
index_col=0) # read data
database = db.Database('data', df) # create database for
biogeme

globals().update(database.variables) # define headers of
columns as variables

# Exclude cases in which either or B was not answered
exclude = ((A == 0) + (B == 0)) >= 1
database.remove(exclude)

# Parameters to be estimated
# Alternative specific constants
ASC_METRO = Beta('ASC_METRO', 0, None, None, 0)
ASC_BT = Beta('ASC_BT', 0, None, None, 0)
ASC_SB = Beta('ASC_SB', 0, None, None, 0)
ASC_SM_E = Beta('ASC_SM_E', 0, None, None, 0)
ASC_SM = Beta('ASC_SM', 0, None, None, 0)
ASC_BIKE = Beta('ASC_BIKE', 0, None, None, 0)
ASC_CAR = Beta('ASC_CAR', 0, None, None, 1)
# Main
B_METRO_WAIT = Beta('B_METRO_WAIT', 0, None, None,
0)
B_MAIN_TIME = Beta('B_MAIN_TIME', 0, None, None, 0)
B_MAIN_COST = Beta('B_MAIN_COST', 0, None, None, 0)
# Egress
B_EGRESS_TIME = Beta('B_EGRESS_TIME', 0, None, None,
0)
B_WALK = Beta('B_WALK', 0, None, None, 0)
B_EGRESS_COST = Beta('B_EGRESS_COST', 0, None, None,
0)
B_EGRESS_COST_S = Beta('B_EGRESS_COST_S', 1, None,
None, 0)
omega = RandomVariable('omega')
density = dist.normalpdf(omega)
B_EGRESS_COST_RND = B_EGRESS_COST +
B_EGRESS_COST_S * omega

# New variables for availability of alternatives
metro_bt = 1
metro_sb = SharedBike
metro_sm = SharedMoped
metro_walk = 1

# Specificacion of utility functions
# Metro alternatives
V1 = ASC_METRO + ASC_BT + B_METRO_WAIT*metro_wt +
B_MAIN_TIME*metro_vt + B_MAIN_COST*metro_cost +
B_EGRESS_TIME*(bt_vt + bt_wt) + B_WALK*bt_walk +
B_EGRESS_COST_RND*bt_cost
V2 = ASC_METRO + ASC_SB + B_METRO_WAIT*metro_wt +
B_MAIN_TIME*metro_vt + B_MAIN_COST*metro_cost +
B_EGRESS_TIME*sbike_vt +
B_EGRESS_COST_RND*sbike_cost
V3 = ASC_METRO + ASC_SM_E +
B_METRO_WAIT*metro_wt + B_MAIN_TIME*metro_vt +
B_MAIN_COST*metro_cost + B_EGRESS_TIME*smoped_vt
+ B_EGRESS_COST_RND*smoped_cost
V4 = ASC_METRO + B_METRO_WAIT*metro_wt +
B_MAIN_TIME*metro_vt + B_MAIN_COST*metro_cost +
B_WALK*walk_t
V5=ASC_SM+B_WALK*smoped2_search+B_MAIN_TIME*s
moped2_vt+B_MAIN_COST*smoped2_cost
V6 = ASC_CAR + B_MAIN_TIME*car_vt +
B_WALK*car_walk+B_MAIN_COST*(car_cost + car_park)
V7 = ASC_BIKE + B_MAIN_TIME*bike_vt
# Associating utility functions with alternatives
V = {1: V1,  2: V2,  3: V3,  4: V4,  5: V5,  6: V6, 7: V7}

# Availability of alternatives
av = {1: metro_bt,
    2: metro_sb,
    3: metro_sm,
    4: metro_walk,
    5: SharedMoped,
    6: Car,
    7: Bike}

# Defining choice model and creating BIOGEME object
condprob = models.logit(V, av, B)
logprob = log(Integrate(condprob*density, 'omega'))
logger = msg.bioMessage()
logger.setGeneral()
biogeme = bio.BIOGEME(database, logprob)
biogeme.modelName = 'ML_Taste_NumInt_EGRESS_COST'
results = biogeme.estimate()
```

ML to capture taste heterogeneity

Example of ML model with panel effects to capture taste heterogeneity for one parameter. All other random parameters are modelled analogously.

```
# ML Model
# Taste heterogeneity: B_MAIN_TIME
# Panel effects
import pandas as pd
import biogeme.database as db
import biogeme.biogeme as bio
from biogeme import models
import biogeme.messaging as msg
from biogeme.expressions import (Beta, Integrate,
DefineVariable, RandomVariable, exp, bioDraws,
PanelLikelihoodTrajectory, MonteCarlo, log)

df = pd.read_csv('data.csv', skipinitialspace=True,
index_col=0)  # read data
database = db.Database('data', df)  # create database for
biogeme

database.panel("ID")

globals().update(database.variables) # define headers of
columns as variables

# Exclude cases in which either or B was not answered
exclude = ((A == 0) + (B == 0)) >= 1
database.remove(exclude)

# Parameters to be estimated
# Alternative specific constants
# ASC_METRO made random to deal with taste
heterogeneity
ASC_METRO = Beta('ASC_METRO', 0, None, None, 0)
ASC_BT = Beta('ASC_BT', 0, None, None, 0)
ASC_SB = Beta('ASC_SB', 0, None, None, 0)
ASC_SM_E = Beta('ASC_SM_E', 0, None, None, 0)
ASC_SM = Beta('ASC_SM', 0, None, None, 0)
ASC_BIKE = Beta('ASC_BIKE', 0, None, None, 0)
ASC_CAR = Beta('ASC_CAR', 0, None, None, 1)

# Parameters to be estimated
# Betas
# Main
B_METRO_WAIT = Beta('B_METRO_WAIT', 0, None, None,
0)

B_MAIN_TIME = Beta('B_MAIN_TIME', 0, None, None, 0)
B_MAIN_TIME_S = Beta('B_MAIN_TIME_S', 1, None, None,
0)
B_MAIN_TIME_RND = B_MAIN_TIME + B_MAIN_TIME_S *
bioDraws('B_MAIN_TIME_RND', 'NORMAL')

B_MAIN_COST = Beta('B_MAIN_COST', 0, None, None, 0)

# Egress
B_EGRESS_TIME = Beta('B_EGRESS_TIME', 0, None, None,
0)
B_WALK = Beta('B_WALK', 0, None, None, 0)
B_EGRESS_COST = Beta('B_EGRESS_COST', 0, None, None,
0)

# New variables for availability of alternatives
metro_bt = 1
metro_sb = SharedBike
metro_sm = SharedMoped
metro_walk = 1

# Specificacion of utility functions
# Metro alternatives
V1 = ASC_METRO + ASC_BT + B_METRO_WAIT*metro_wt +
B_MAIN_TIME_RND*metro_vt +
B_MAIN_COST*metro_cost + B_EGRESS_TIME*(bt_vt +
bt_wt) + B_WALK*bt_walk + B_EGRESS_COST*bt_cost
V2 = ASC_METRO + ASC_SB + B_METRO_WAIT*metro_wt +
B_MAIN_TIME_RND*metro_vt +
B_MAIN_COST*metro_cost + B_EGRESS_TIME*sbike_vt +
B_EGRESS_COST*sbike_cost
V3 = ASC_METRO + ASC_SM_E +
B_METRO_WAIT*metro_wt +
B_MAIN_TIME_RND*metro_vt +
B_MAIN_COST*metro_cost + B_EGRESS_TIME*smoped_vt
+ B_EGRESS_COST*smoped_cost
V4 = ASC_METRO + B_METRO_WAIT*metro_wt +
B_MAIN_TIME_RND*metro_vt +
B_MAIN_COST*metro_cost + B_WALK*walk_t

# Other alternatives
V5 = ASC_SM + B_WALK*smoped2_search +
B_MAIN_TIME_RND*smoped2_vt +
B_MAIN_COST*smoped2_cost
V6 = ASC_CAR + B_MAIN_TIME_RND*car_vt +
B_WALK*car_walk + B_MAIN_COST*(car_cost + car_park)
V7 = ASC_BIKE +  B_MAIN_TIME_RND*bike_vt

# Associating utility functions with alternatives
V = {1: V1, 2: V2, 3: V3, 4: V4, 5: V5, 6: V6, 7: V7}

# Availability of alternatives
av = {1: metro_bt, 2: metro_sb, 3: metro_sm, 4: metro_walk,
5: SharedMoped, 6: Car, 7: Bike}

# Defining choice model and creating BIOGEME object
obsprob = models.logit(V, av, B)
condprobIndiv = PanelLikelihoodTrajectory(obsprob)
logprob = log(MonteCarlo(condprobIndiv))
logger = msg.bioMessage()
logger.setDetailed()
biogeme = bio.BIOGEME(database, logprob,
numberOfDraws = 2000)
biogeme.modelName = 'ML_Taste&Panel_MAIN_TIME'
results = biogeme.estimate()
```

C.4 Results – Taste heterogeneity

B_EGRESS_COST								
	Only taste heterogeneity				*Taste heterogeneity and Panel*			
			Rho-square	**1.70E-01**			*Rho-square*	*2.36E-01*
Name	**Value**	**Rob. SE**	**Rob. t-test**	**Rob. p-value**	*Value*	*Rob. SE*	*Rob. t-test*	*Rob. p-value*
ASC_BIKE	-0.275	0.107	-2.58	0.00999	*-0.346*	*0.133*	*-2.6*	*0.00945*
ASC_BT	0.676	0.231	2.93	0.00342	*1.76*	*0.273*	*6.45*	*1.11E-10*
ASC_METRO	-0.858	0.194	-4.41	0.0000102	*-0.685*	*0.201*	*-3.42*	*0.000637*
ASC_SB	-0.864	0.243	-3.56	0.000378	*0.181*	*0.292*	*0.618*	*0.537*
ASC_SM	-1.38	0.0812	-17	0	*-1.45*	*0.119*	*-12.2*	*0*
ASC_SM_E	-0.941	0.258	-3.65	0.000259	*0.114*	*0.322*	*0.355*	*0.723*
B_EGRESS_COST	-0.425	0.0791	-5.37	7.84E-08	*-1.65*	*0.14*	*-11.8*	*0*
B_EGRESS_COST_S	-2.25E-05	0.0000058	-3.88	0.000104	*1.37*	*0.0813*	*16.8*	*0*
B_EGRESS_TIME	-0.0389	0.012	-3.25	0.00115	*-0.0474*	*0.0117*	*-4.04*	*0.0000544*
B_MAIN_COST	-0.0932	0.0107	-8.68	0	*-0.101*	*0.0107*	*-9.41*	*0*
B_MAIN_TIME	-0.0337	0.00507	-6.64	3.05E-11	*-0.0404*	*0.00451*	*-8.96*	*0*
B_METRO_WAIT	-0.0144	0.0222	-0.648	0.517	*-0.0441*	*0.0194*	*-2.28*	*0.0228*
B_WALK	-0.0638	0.0101	-6.29	3.17E-10	*-0.0745*	*0.00905*	*-8.23*	*2.22E-16*

Legend: highlighted green: significant at 95% confidence interval; highlighted blue: significant at 99% confidence interval

B_EGRESS_TIME								
	Only taste heterogeneity				*Taste heterogeneity and Panel*			
			Rho-square	**1.70E-01**			*Rho-square*	*2.43E-01*
Name	**Value**	**Rob. SE**	**Rob. t-test**	**Rob. p-value**	*Value*	*Rob. SE*	*Rob. t-test*	*Rob. p-value*
ASC_BIKE	-0.275	0.107	-2.58	0.00997	*-0.38*	*0.134*	*-2.83*	*0.00462*
ASC_BT	0.676	0.231	2.93	0.00344	*1.63*	*0.279*	*5.81*	*6.07E-09*
ASC_METRO	-0.858	0.194	-4.41	0.0000102	*-0.728*	*0.204*	*-3.58*	*0.000346*
ASC_SB	-0.864	0.243	-3.56	0.000374	*0.0823*	*0.3*	*0.275*	*0.784*
ASC_SM	-1.38	0.0812	-17	0	*-1.46*	*0.119*	*-12.3*	*0*
ASC_SM_E	-0.942	0.258	-3.66	0.000257	*-0.0131*	*0.32*	*-0.0408*	*0.967*
B_EGRESS_COST	-0.425	0.0791	-5.37	0.000000079	*-0.508*	*0.0819*	*-6.2*	*5.55E-10*
B_EGRESS_TIME	-0.0389	0.012	-3.25	0.00115	*-0.236*	*0.0227*	*-10.4*	*0*
B_EGRESS_TIME_S	-4.8E-06	1.13E-06	-4.24	0.0000219	*0.239*	*0.0152*	*15.7*	*0*
B_MAIN_COST	-0.0932	0.0107	-8.68	0	*-0.102*	*0.0109*	*-9.43*	*0*
B_MAIN_TIME	-0.0337	0.00507	-6.64	3.06E-11	*-0.0417*	*0.00461*	*-9.04*	*0*
B_METRO_WAIT	-0.0144	0.0222	-0.648	0.517	*-0.00989*	*0.0194*	*-0.509*	*0.61*
B_WALK	-0.0638	0.0101	-6.29	3.14E-10	*-0.0808*	*0.00948*	*-8.52*	*0*

Legend: highlighted green: significant at 95% confidence interval; highlighted blue: significant at 99% confidence interval

B_MAIN_COST

		Only taste heterogeneity			*Taste heterogeneity and Panel*			
			Rho-square	1.70E-01			*Rho-square*	*2.26E-01*
Name	**Value**	**Rob. SE**	**Rob. t-test**	**Rob. p-value**	*Value*	*Rob. SE*	*Rob. t-test*	*Rob. p-value*
ASC_BIKE	-0.287	0.127	-2.26	0.0237	-1.19	0.171	-10.7	3.56E-12
ASC_BT	0.618	0.236	2.62	0.00883	0.543	0.238	2.23	0.0225
ASC_METRO	-0.777	0.198	-3.91	0.000091	-1.03	0.212	-5.17	0.00000116
ASC_SB	-0.93	0.25	-3.73	0.000193	-1.03	0.272	-4.08	0.000154
ASC_SM	-0.709	0.201	-3.53	0.00041	-0.213	0.291	-0.868	0.465
ASC_SM_E	-1.01	0.264	-3.84	0.000125	-1.1	0.294	-4.12	0.000189
B_EGRESS_COST	-0.43	0.0793	-5.43	5.74E-08	-0.437	0.0721	-5.46	1.34E-09
B_EGRESS_TIME	-0.0393	0.012	-3.27	0.00107	-0.0427	0.0105	-3.4	0.0000477
B_MAIN_COST	-0.098	0.0143	-6.86	6.9E-12	-0.29	0.0372	-10.8	7.33E-15
B_MAIN_COST_S	0.0783	0.014	5.58	2.45E-08	0.442	0.064	13.6	5.02E-12
B_MAIN_TIME	-0.0362	0.00548	-6.61	3.86E-11	-0.0421	0.00489	-7.16	0
B_METRO_WAIT	-0.0203	0.0228	-0.89	0.374	-0.00975	0.0195	-0.405	0.617
B_WALK	-0.0693	0.0109	-6.38	1.76E-10	-0.079	0.00963	-7.24	2.22E-16

Legend: highlighted green: significant at 95% confidence interval; highlighted blue: significant at 99% confidence interval

B_MAIN_TIME

		Only taste heterogeneity			*Taste heterogeneity and Panel*			
			Rho-square	1.70E-01			*Rho-square*	*2.36E-01*
Name	**Value**	**Rob. SE**	**Rob. t-test**	**Rob. p-value**	*Value*	*Rob. SE*	*Rob. t-test*	*Rob. p-value*
ASC_BIKE	-0.277	0.107	-2.58	0.00993	-0.372	0.146	-2.54	0.011
ASC_BT	0.675	0.231	2.91	0.00356	0.683	0.242	2.83	0.00469
ASC_METRO	-0.86	0.196	-4.4	0.0000109	-0.937	0.229	-4.09	0.0000441
ASC_SB	-0.867	0.243	-3.56	0.000371	-0.914	0.275	-3.33	0.000879
ASC_SM	-1.38	0.0814	-17	0	-1.41	0.134	-10.5	0
ASC_SM_E	-0.944	0.258	-3.66	0.000252	-0.992	0.294	-3.37	0.000739
B_EGRESS_COST	-0.426	0.0792	-5.37	7.79E-08	-0.456	0.0712	-6.41	1.47E-10
B_EGRESS_TIME	-0.0391	0.012	-3.26	0.00113	-0.0496	0.0109	-4.56	0.0000052
B_MAIN_COST	-0.0935	0.0108	-8.63	0	-0.1	0.0118	-8.49	0
B_MAIN_TIME	-0.0337	0.00511	-6.6	4.22E-11	-0.0409	0.00586	-6.97	3.19E-12
B_MAIN_TIME_S	-0.018	0.0331	-0.544	0.586	0.155	0.0073	21.2	0
B_METRO_WAIT	-0.0139	0.0226	-0.616	0.538	-0.0095	0.0246	-0.387	0.699
B_WALK	-0.0641	0.0102	-6.26	3.93E-10	-0.0763	0.00969	-7.88	3.33E-15

Legend: highlighted green: significant at 95% confidence interval; highlighted blue: significant at 99% confidence interval

B_WALK								
	Only taste heterogeneity				*Taste heterogeneity and Panel*			
			Rho-square	1.70E-01			*Rho-square*	*2.25E-01*
Name	Value	Rob. SE	Rob. t-test	Rob. p-value	*Value*	*Rob. SE*	*Rob. t-test*	*Rob. p-value*
ASC_BIKE	-0.275	0.107	-2.58	0.01	*-0.66*	*0.137*	*-4.82*	*1.43E-06*
ASC_BT	0.676	0.231	2.93	0.00343	*0.89*	*0.275*	*3.24*	*1.21E-03*
ASC_METRO	-0.858	0.194	-4.41	0.0000103	*-0.961*	*0.24*	*-4.01*	*6.15E-05*
ASC_SB	-0.864	0.243	-3.56	0.000375	*-0.995*	*0.293*	*-3.4*	*6.76E-04*
ASC_SM	-1.38	0.0812	-17	0	*-1.4*	*0.122*	*-11.5*	*0.00E+00*
ASC_SM_E	-0.942	0.258	-3.66	0.000257	*-0.985*	*0.319*	*-3.09*	*2.02E-03*
B_EGRESS_COST	-0.425	0.0791	-5.37	7.83E-08	*-0.478*	*0.0787*	*-6.08*	*1.20E-09*
B_EGRESS_TIME	-0.0389	0.012	-3.25	0.00115	*-0.0418*	*0.0109*	*-3.83*	*1.28E-04*
B_MAIN_COST	-0.0932	0.0107	-8.68	0	*-0.0922*	*0.0108*	*-8.5*	*0.00E+00*
B_MAIN_TIME	-0.0337	0.00507	-6.64	3.08E-11	*-0.0252*	*0.00474*	*-5.31*	*1.11E-07*
B_METRO_WAIT	-0.0144	0.0222	-0.649	0.516	*-0.0162*	*0.0182*	*-0.889*	*3.74E-01*
B_WALK	-0.0638	0.0101	-6.29	3.12E-10	*-0.17*	*0.0162*	*-10.5*	*0.00E+00*
B_WALK_S	-0.000148	0.00322	-0.046	0.963	*-0.196*	*0.0202*	*-9.73*	*0.00E+00*

Legend: highlighted green: significant at 95% confidence interval; highlighted blue: significant at 99% confidence interval

B_WAIT_METRO				
	Taste heterogeneity and Panel			
			Rho-square	2.47E-01
Name	Value	Rob. SE	Rob. t-test	Rob. p-value
ASC_BIKE	-0.45	0.144	-3.12	0.0018
ASC_BT	0.603	0.238	2.53	0.0113
ASC_METRO	-0.838	0.231	-3.63	0.000286
ASC_SB	-0.99	0.276	-3.59	0.000326
ASC_SM	-1.57	0.127	-12.3	0
ASC_SM_E	-1.05	0.297	-3.54	0.000403
B_EGRESS_COST	-0.462	0.0727	-6.35	2.14E-10
B_EGRESS_TIME	-0.0433	0.0104	-4.16	0.0000312
B_MAIN_COST	-0.11	0.0114	-9.66	0
B_MAIN_TIME	-0.0521	0.00617	-8.45	0
B_METRO_WAIT	-0.355	0.0732	-4.85	0.00000123
B_METRO_WAIT_S	1.09	0.107	10.1	0
B_WALK	-0.0785	0.0101	-7.74	9.77E-15

Legend: highlighted green: significant at 95% confidence interval; highlighted blue: significant at 99% confidence interval

ALL BETAS				
	Taste heterogeneity and Panel			
			Rho-square	**3.01E-01**
Name	**Value**	**Rob. SE**	**Rob. t-test**	**Rob. p-value**
ASC_BIKE	-0.658	0.145	-4.54	0.00000551
ASC_BT	1.13	0.31	3.66	0.00025
ASC_METRO	-1.01	0.259	-3.91	0.000094
ASC_SB	-0.665	0.337	-1.98	0.0482
ASC_SM	-1.58	0.127	-12.4	0
ASC_SM_E	-0.717	0.364	-1.97	0.0488
B_EGRESS_COST	-0.673	0.113	-5.95	2.65E-09
B_EGRESS_COST_S	0.422	0.121	3.48	0.000504
B_EGRESS_TIME	-0.13	0.0188	-6.88	5.95E-12
B_EGRESS_TIME_S	0.153	0.0133	11.5	0
B_MAIN_COST	-0.112	0.0118	-9.5	0
B_MAIN_COST_S	0.924	0.0876	10.5	0
B_MAIN_TIME	-0.0443	0.00594	-7.46	8.46E-14
B_MAIN_TIME_S	0.0221	0.0232	0.952	0.341
B_METRO_WAIT	-0.068	0.0304	-2.24	0.0253
B_METRO_WAIT_S	0.0715	0.0771	0.927	0.354
B_WALK	-0.14	0.0134	-10.4	0
B_WALK_S	-0.122	0.0119	-10.3	0

Legend: highlighted green: significant at 95% confidence interval; highlighted blue: significant at 99% confidence interval

C.5 Syntax – ML to capture ASC heterogeneity

```
# ML Model for the whole trip
# Alternative specific variance

import pandas as pd
import biogeme.database as db
import biogeme.biogeme as bio
from biogeme import models
import biogeme.messaging as msg
from biogeme.expressions import (Beta, Integrate,
DefineVariable, RandomVariable, exp, bioDraws,
PanelLikelihoodTrajectory, MonteCarlo, log)

df = pd.read_csv('data.csv', skipinitialspace=True,
index_col=0) # read data
database = db.Database('data', df) # create database for
biogeme

database.panel("ID")

globals().update(database.variables)

# Exclude cases in which either or B was not answered
exclude = ((A == 0) + (B == 0)) >= 1
database.remove(exclude)

# Parameters to be estimated
ASC_METRO = Beta('ASC_METRO', 0, None, None, 0)
SIGMA_METRO = Beta('SIGMA_METRO', 1, None, None, 0)
ASC_METRO_RND = ASC_METRO + SIGMA_METRO *
bioDraws('ASC_METRO_RND', 'NORMAL')

ASC_BT = Beta('ASC_BT', 0, None, None, 0)
SIGMA_BT = Beta('SIGMA_BT', 1, None, None, 0)
ASC_BT_RND = ASC_BT + SIGMA_BT *
bioDraws('ASC_BT_RND', 'NORMAL')

ASC_SB = Beta('ASC_SB', 0, None, None, 0)
SIGMA_SB = Beta('SIGMA_SB', 1, None, None, 0)
ASC_SB_RND = ASC_SB + SIGMA_SB *
bioDraws('ASC_SB_RND', 'NORMAL')

ASC_SM_E = Beta('ASC_SM_E', 0, None, None, 0)
SIGMA_SM_E = Beta('SIGMA_SM_E', 1, None, None, 0)
ASC_SM_E_RND = ASC_SM_E + SIGMA_SM_E *
bioDraws('ASC_SM_E_RND', 'NORMAL')

ASC_SM = Beta('ASC_SM', 0, None, None, 0)

ASC_BIKE = Beta('ASC_BIKE', 0, None, None, 0)
SIGMA_BIKE = Beta('SIGMA_BIKE', 1, None, None, 0)
ASC_BIKE_RND = ASC_BIKE + SIGMA_BIKE *
bioDraws('ASC_BIKE_RND', 'NORMAL')

ASC_CAR = Beta('ASC_CAR', 0, None, None, 1)
SIGMA_CAR = Beta('SIGMA_ CAR ', 1, None, None, 0)
ASC_ CAR _RND = ASC_ CAR + SIGMA_ CAR *
bioDraws('ASC_ CAR _RND', 'NORMAL')
B_METRO_WAIT = Beta('B_METRO_WAIT', 0, None, None,
0)
B_MAIN_TIME = Beta('B_MAIN_TIME', 0, None, None, 0)
B_MAIN_COST = Beta('B_MAIN_COST', 0, None, None, 0)
B_EGRESS_TIME = Beta('B_EGRESS_TIME', 0, None, None,
0)
B_WALK = Beta('B_WALK', 0, None, None, 0)
B_EGRESS_COST = Beta('B_EGRESS_COST', 0, None, None,
0)

# New variables for availability of alternatives
metro_bt = 1
metro_sb = SharedBike
metro_sm = SharedMoped
metro_walk = 1

# Specificacion of utility functions
V1 = ASC_METRO_RND + ASC_BT_RND +
B_METRO_WAIT*metro_wt + B_MAIN_TIME*metro_vt +
B_MAIN_COST*metro_cost + B_EGRESS_TIME*(bt_vt +
bt_wt) + B_WALK*bt_walk + B_EGRESS_COST*bt_cost #
Metro & BT

V2 = ASC_METRO_RND + ASC_SB_RND +
B_METRO_WAIT*metro_wt + B_MAIN_TIME*metro_vt +
B_MAIN_COST*metro_cost + B_EGRESS_TIME*sbike_vt +
B_EGRESS_COST*sbike_cost # Metro & Shared Bike

V3 = ASC_METRO_RND + ASC_SM_E_RND +
B_METRO_WAIT*metro_wt + B_MAIN_TIME*metro_vt +
B_MAIN_COST*metro_cost + B_EGRESS_TIME*smoped_vt
+ B_EGRESS_COST*smoped_cost # Metro & Shared Bike

V4 = ASC_METRO_RND + B_METRO_WAIT*metro_wt +
B_MAIN_TIME*metro_vt + B_MAIN_COST*metro_cost +
B_WALK*walk_t

# Other alternatives
V5 = ASC_SM + B_WALK*smoped2_search +
B_MAIN_TIME*smoped2_vt +
B_MAIN_COST*smoped2_cost
V6 = ASC_CAR_RND + B_MAIN_TIME*car_vt +
B_WALK*car_walk + B_MAIN_COST*(car_cost + car_park)
V7 = ASC_BIKE_RND + B_MAIN_TIME*bike_vt

# Associating utility functions with alternatives
V = {1: V1, 2: V2, 3: V3, 4: V4, 5: V5, 6: V6, 7: V7}
# Availability of alternatives
av = {1: metro_bt, 2: metro_sb, 3: metro_sm, 4: metro_walk,
5: SharedMoped, 6: Car, 7: Bike}

# Defining choice model and creating BIOGEME object
obsprob = models.logit(V, av, B)
condprobIndiv = PanelLikelihoodTrajectory(obsprob hoci
logprob = log(MonteCarlo(condprobIndiv))
logger = msg.bioMessage()
logger.setDetailed()
biogeme = bio.BIOGEME(database, logprob,
numberOfDraws = 16000)
biogeme.modelName = 'ML_Taste&Panel_ASC'
```

C.6 Results – ML to capture ASC heterogeneity

ALL ASC				
	Taste heterogeneity and Panel			
			Rho-square	3.93E-01
Parameter	**Value**	**Rob. SE**	**Rob. t-test**	**Rob. p-value**
ASC_BIKE	-0.561	0.284	-1.97	0.0487
ASC_BT	0.373	0.361	1.03	0.301
ASC_METRO	-1.07	0.339	-3.15	0.00162
ASC_SB	-1.89	0.426	-4.43	0.00000934
ASC_SM	-1.7	0.202	-8.43	0
ASC_SM_E	-2.19	0.499	-4.39	0.0000111
B_EGRESS_COST	-0.715	0.112	-6.37	1.9E-10
B_EGRESS_TIME	-0.0734	0.0167	-4.4	0.000011
B_MAIN_COST	-0.186	0.0191	-9.74	0
B_MAIN_TIME	-0.0711	0.00803	-8.85	0
B_METRO_WAIT	-0.0307	0.0324	-0.947	0.344
B_WALK	-0.11	0.0137	-7.98	1.55E-15
SIGMA_BIKE	3.02	0.247	12.2	0
SIGMA_BT	2.36	0.171	13.8	0
SIGMA_CAR	2.45	0.197	12.4	0
SIGMA_METRO	2.37	0.169	14.1	0
SIGMA_SB	-2.09	0.183	-11.4	0
SIGMA_SM_E	-2.36	0.286	-8.27	2.22E-16