Shared micromobility and public transport integration - A mode choice study using stated preference data

Montes, Alejandro; Geržinic, Nejc; Veeneman, Wijnand; van Oort, Niels; Hoogendoorn, Serge

DOI
10.1016/j.retrec.2023.101302

Publication date
2023

Document Version
Final published version

Published in
Research in Transportation Economics

Citation (APA)
Montes, A., Geržinic, N., Veeneman, W., van Oort, N., & Hoogendoorn, S. (2023). Shared micromobility and public transport integration - A mode choice study using stated preference data. *Research in Transportation Economics*, *99*, Article 101302. https://doi.org/10.1016/j.retrec.2023.101302

Research in Transportation Economics 99 (2023) 101302

Contents lists available at ScienceDirect

Research in Transportation Economics

journal homepage: www.elsevier.com/locate/retrec

Research paper

Shared micromobility and public transport integration - A mode choice study using stated preference data

Alejandro Montes [1], Nejc Geržinic, Wijnand Veeneman, Niels van Oort [*], Serge Hoogendoorn

Department of Transport & Planning, Faculty of Civil Engineering and Geosciences, Delft University of Technology, 2628CN, Delft, the Netherlands

A R T I C L E I N F O

JEL classification:
R3
C5
C9

Keywords:
Shared micromobility
Public transport
Mode choice
Choice modelling
Stated choice

A B S T R A C T

This paper uses stated preference data collected in the city of Rotterdam and discrete choice modelling techniques to study the relationship between public transport and shared micromobility. It assumes a hypothetical condition of integrated systems and studies the relationships of complement and competition between these modes. The findings suggest that shared micromobility modes are viable alternatives as egress modes for metro trips. Shared micromobility can be seen as a complement to metro, yet shared e-mopeds proved to also be a viable option as individual modes for long-distance trips. Different characteristics proved to be important in choices in this context: frequency of public transport use, previous use of shared micromobility, and age. Considering the results obtained, collaboration between shared micromobility and transit operators might benefit them as well as travellers. Collaborations should be designed so that they help travellers to decrease total travel time, even if it implies longer egress legs. However, the costs of these shared modes should not be as high as to prevent travellers to use them as egress alternatives. Finally, young travellers and frequent transit users could be specifically targeted, as they showed to have a better perception of shared micromobility.

1. Introduction

Climate change, together with many other environmental challenges, has brought the need for a more sustainable society. The transport sector is closely related to that challenge. 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). In addition, recent years have seen the emergence and growth of new mobility solutions. Some of them are seen as potential enablers toward the more sustainable society that is pursued. For instance, shared micromobility is a concept currently receiving special attention in this regard (Oeschger et al., 2020). It refers to small human and electric-powered vehicles, such as bicycles, e-bikes and e-scooters (standing and seating). For the remainder of this paper, we refer to seating e-scooters as e-mopeds. Employing different rental schemes these vehicles are provided on a short-term basis. The rental can be either station-based or dockless (also known as free-floating). While the former refers to schemes in which rental must take place in specific locations acting as stations, the latter is characterised by the ability of rentals to be started and ended almost anywhere in a city.

As many cities experience the effects of the emergence and growth of shared micromobility, its relationship with traditional public transport has become a topic of interest. While collaborations between transit and shared micromobility providers are becoming increasingly common, the effects of said collaborations are still uncertain. The relationship between shared micromobility and public transport has been widely studied in recent years. Even though conclusions vary among studies, many agree on the potential of the combination of public transport with shared micromobility 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). Two strong arguments arise supporting the idea of shared micromobility being a potential complement to public transport. First, shared micromobility can serve as access/egress modes, and as such help improve the accessibility to transit services (Böcker et al., 2020; Torabi et al., 2022; van Mil et al., 2020). Second, said improvement of first- and last-mile is highly correlated with consequential increases in coverage and accessibility of public transport (Geržinič et al., 2023; Ji et al., 2018; McLeod et al., 2017; Shaheen, 2016). In that regard, Leth et al. (2017) suggest that bicycle-sharing services in low-density areas of a city might

* Corresponding author. Department of Transport and Planning, Delft University of Technology, Stevinweg 1, 2628CN, Delft, the Netherlands.
E-mail address: N.vanOort@tudelft.nl (N. van Oort).
[1] Present address: Goudappel Group, P.O. Box 161, 7400 AD, Deventer, the Netherlands

https://doi.org/10.1016/j.retrec.2023.101302
Received 29 November 2022; Received in revised form 13 May 2023; Accepted 16 May 2023
Available online 31 May 2023

improve the coverage of transit. In addition, studies based on observed behaviour data have analysed the spatial distribution of shared modes trips with respect to public transport networks. Böcker et al. (2020) found that in Oslo 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 in peripheral areas of the transit network, in which connections are not well developed.

Nonetheless, some argue that shared micromobility does not only complement but also competes against transit. Leth et al. (2017) and Van Marsbergen et al. (2022) highlight that in high-density areas bike-sharing represents a direct and faster option than public transport. Something similar holds for congested parts of transit networks, like city centres, where shared micromobility 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 if the latter are faster (Leth et al., 2017).

The relationship between shared micromobility and public transport is thought to highly depend on how well integrated the modes are. For instance, Oeschger et al. (2020) highlight that to promote and improve the integration between shared mobility and public transport, the systems should be planned together - as a whole-considering the synergy between them. To encourage multimodality (integrating public transport and shared micromobility), conditions to make the latter available for access and egress are argued to be needed. According to Böcker et al. (2020), shared mobility use frequencies are positively affected by its proximity to terminal/final stops of public transport lines. Likewise, Yan et al. (2020) highlight the importance of land use and population density around public transport stations for the adoption of bicycle-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 by making transfers more efficient and improving user-friendliness (Böcker et al., 2020; Ma et al., 2020; Oeschger et al., 2020; Shaheen, 2016).

To sum up, different studies have been performed in recent years to understand the relationship between public transport and shared micromobility. They have mostly focused on analysing the current use of shared micromobility, the perception of users towards them, or mode choice in the context of first/last mile travel. To the best of our knowledge, mode choice in a multimodal network with integrated services, including competition and complement between shared micromobility and transit is still to be studied more in detail.

This paper studies mode choice related to public transport and shared micromobility, using the Dutch city of Rotterdam and its neighbouring municipalities as study area. In the study, shared micromobility is limited to free-floating shared e-mopeds and bicycles, as they are the most common in The Netherlands, and a hypothetical condition of integrated systems is assumed. It contributes to the body of literature on this topic, by including an analysis of shared micromobility not only as first/last mile enablers but also as alternatives for trips from origin to destination.

The remaining of this paper is structured as follows: Section 2 presents the methodology in detail, whereas Section 3 presents the overview of the results obtained. Finally, Section 4 presents the main conclusions of the study.

2. Methodology

This study includes mode choices both in the main leg as well as in the egress part of public transport trips. As a result, the choices included in the stated choice experiment and thus the estimated models must include both types of choices. This study focuses on home-based trips, since for their egress it is more likely that travellers do not possess private vehicles.

2.1. Survey design

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 micromobility and public transport are fully integrated, the use of stated preference data 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 is designed. Designing a specific experiment for the project allows us to create the experiment in such a way, that it fits as much as possible the scope and goal of the research.

A 2-step approach is defined for the experiment. It includes two transport mode decisions related to one another, for each choice situation. Each choice situation assumes a trip from home to a leisure/commute destination within the city. In the first choice task (step 1), respondents have to select their preferred egress mode from a transit station, assuming they had arrived there by metro (see Fig. 1). The possible alternatives are walking, public transport (tram or bus), shared bicycle and shared e-moped. This choice task intends to analyse shared micromobility as a last-mile enabler for metro trips. In addition, it also allows the analysis of perception towards these modes in comparison with other egress modes. For the remainder of this paper, this choice task is referred to as the "Egress task".

Secondly, the complete trip chain is evaluated (see Fig. 2). The previously selected egress alternative is included in the multimodal option (where the metro is the main mode), with additional unimodal alternatives (car, (private) bicycle and shared e-moped). This choice task allows us to estimate the level of competition between metro and shared micromobility. For the remainder of this paper, this choice situation is called the "*Complete trip task*". Choice sets are subject to the availability of modes for respondents, as well as their ability to drive/use those specific modes. For instance, for respondents that do not possess a valid driving license, the car and shared e-moped alternatives are not available.

This study is developed under a hypothetical scenario in which shared micromobility 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 micromobility scheme, day of the week, COVID-19, luggage, and weather. Every respondent faces a single context that is kept fixed for all scenarios. Context is kept for all respondents, except for trip purpose. This factor is varied randomly across the sample. For simplification, it is decided to include it only making a distinction between commute and non-commute trips. An example of a choice context is presented in Table 1.

The attributes of each alternative represent the characteristics of the trip depending on the properties of each transport mode. Attributes included in this study are based on different studies: (Arentze & Molin,

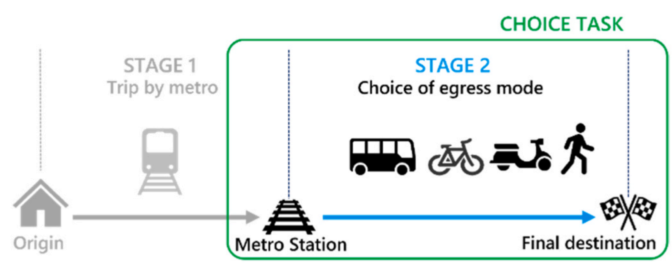

Fig. 1. Choice task explanation: Egress mode choice.

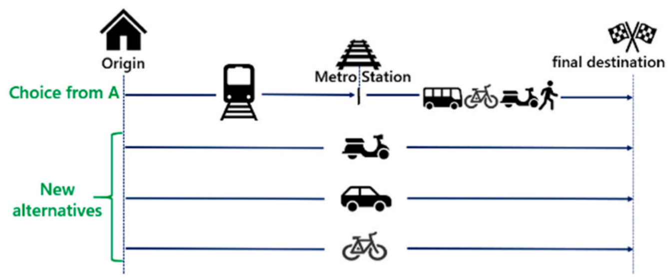

Fig. 2. Choice task explanation: Complete trip mode choice.

Table 1
Example of choice context (Commuter trip).

Attribute	Context
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
Trip purpose	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

2013; van Kuijk et al., 2022), and on the objectives and scope of this research. It is decided to include cost and time attributes, making the necessary distinction between their components. The overview of the attributes included per alternative in egress and complete trip tasks are displayed in Table 2 and Table 3 respectively.

To obtain realistic attribute level values, different origin-destination combinations within the Rotterdam region are tested. To determine travel times, the most popular trip-planning apps in The Netherlands are used: *Google Maps* (*Google Maps,* 2021), *9292* (9292, 2021) and *RET planner app* (*Optimaal OV - RET, 2021*). Regarding costs, information available on the webpages of RET and shared micromobility providers are used as a basis (*Check.*, 2021; *Felyx - Beat the Streets*, 2021; *Optimaal OV - RET, 2021*; Donkey Republic, 2021; GO Sharing, 2021; Mobike, 2021; OV-fiets, 2021). To estimate the impact of possible pricing schemes and policies, the range of attributes is expanded beyond the range of current values. Table 4 provides an overview of the attribute levels varied for the egress task, while Table 5 presents the ones associated with the complete trip task.

The experimental design is determined using the software *Ngene* (Choicemetrics, 2018, p. 241). The alternatives are labelled, meaning that the name of the alternatives represents characteristics not varied in the experiment (*e.g. car, shared bicycle, bus, etc*). This type of design allows for the specification of 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.

We employ a D-efficient design, which aims to maximise the trade-offs between parameters and allows us to obtain significant parameter values with fewer respondents. To be able to generate these types of designs, prior information on the parameter values is required. As similar studies have been performed in recent years, it is possible to

Table 2
Overview of attributes per alternative – Egress task.

Attributes/Alternatives	Bus/ Tram	Shared bicycle	Shared e-moped	Walking
Waiting Time	X			
In-vehicle time	X	X	X	
Walking time to destination	X			X
Travel cost		X	X	

Table 3
Overview of attributes per alternative - Complete trip task.

Attributes/ Alternatives	Multimodal trip		Private Bicycle	Shared e-moped	Car
	Metro	Egress			
Waiting Time	X	*Same as in egress mode choice (see Table 2)*			
In-vehicle time	X		X	X	X
Walking time to destination					X
Searching time				X	
Travel cost	X			X	X
Parking Cost					X

Table 4
Attribute levels – Egress mode choice.

Attribute/ Alternative	Bus/Tram	Shared bicycle	Shared e-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 5
Attribute levels – Complete trip mode choice.

Attribute/ Alternative	Metro	Private Bicycle	Shared e-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

obtain reliable priors, predominantly from two previous studies: the basis is the study by Arentze and Molin (2013), while van Kuijk et al. (2022) is used for priors not possible to estimate from the former study. Priors based on van Kuijk et al. (2022) are scaled to maintain consistency with the priors from Arentze and Molin (2013). To scale the priors, common parameters between studies are found, and their ratio is used as a correction factor. To test for non-linearity effects, attributes are defined with three levels. To maintain attribute level balance, a design with nine choice sets is selected. As respondents are presented with two choice tasks for each choice set (the Egress task and Complete trip task), this results in a total of 18 choice tasks per respondent.

In addition to the stated choice experiment, questions regarding the respondents' socio-demographics and transport-related information are also asked. This information is collected with two main objectives. Firstly, to evaluate their interaction effects with mode choices. Second, to review the representativeness of the sample. The information collected is summarized in Table 6.

2.2. Model specification and estimation

The stated choice experiment as designed in this study allows for the estimation of multimodal mode choice models including seven different alternatives. The estimation of the models is performed using *PandasBiogeme,* an open-source *Python* package specialised in the

Table 6
Information from the survey.

Transport related	Sociodemographics
Car ownership	Age
Bicycle ownership	Occupation
Car driving license	Level of education
Moped driving license	Gender
Familiarity with shared micromobility	Income
Previous use of shared micromobility	Household structure
Current public transport frequency of use	

computation of discrete choice models (Bierlaire, 2020, p. 22). All models are developed for the complete trip so that both choices per scenario (i.e. egress and complete trip task) are included in one single model.

All models estimated are based on the concept of Random Utility maximisation. This concept 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 (Ben-Akiva & Bierlaire, 2000). Two types of models are included in the study: Multinomial logit (MNL) and mixed logit (ML).

2.2.1. Multinomial logit model (MNL)

Firstly, we define an MNL model, which is used as the base for all further models estimated in this research. The utility functions for all alternatives follow the same structure: they are composed of an Alternative specific constant (ASC), time parameters and cost parameters, both with their respective attributes. ASC parameters are defined per each separate mode. Hence, multimodal options (e.g. metro and shared bicycle) have two ASC in their utilities. Although most of the parameters are generic, some are only applicable to a certain mode (e.g. waiting time for metro). A distinction is made between time and cost parameters for main and egress legs. A generic utility function is presented in Equation (1).

$$U_i = ASC_i + \beta_{time1} * time1 + \ldots + \beta_{timeN} * timeN + \beta_{cost1} * cost1 + \ldots + \beta_{costM} * costM \tag{1}$$

In addition to the base model, models with interaction effects are estimated to study the influence of socio-demographic characteristics on choices. As trip purpose was varied by design in the experiment, its effects are also evaluated. Each characteristic is modelled separately to have a clear estimation of its effects and relevance. For each characteristic, three models are estimated, each evaluating effects on different types of parameters: ASC, cost, and time. Dummy coding is adopted as the method to include the interactions.

2.2.2. Mixed logit model (ML)

To deal with the shortcomings of the MNL, we employ the Mixed logit model (ML). It allows us to capture three things that the standard MNL approach cannot: nesting of alternatives, taste heterogeneity and panel effects. It does so by allowing the addition of random parameter variation, unrestricted substitution patterns and correlation in unobserved factors of observations over time (Train, 2002). It is decided to divide this part of the modelling into two main parts. The first part focuses on nesting effects and the second on heterogeneity in both preferences and tastes. All models are estimated with panel effects, and Monte-Carlo simulation is adopted as the solving method. We assumed the random parameters to be normally distributed. Accordingly, for each normally distributed parameter, two values are estimated: its mean value, and its associated SIGMA associated with its variance.

2.3. Data collection and sample

The survey was implemented using an online questionnaire developed using the online tool *Qualtrics*. Considering the study area, the survey is distributed in Dutch. Participants are recruited using a commercial panel. It allows us to control characteristics of the respondents that are desired according to the objectives of the study. The only hard constraint applied to the sample is the need for people living in the area of study: Rotterdam and neighbouring municipalities. The choice context was randomly assigned to respondents so that a similar number of responses were for commuting trips as for non-commuting trips. A total of 487 valid responses were collected for the survey. The overview of the sample and the comparison to the population statistics of the Rotterdam area is depicted in Table 7.

3. Results

3.1. Descriptive statistics

First, it is considered important to do a general examination of the choices made by respondents. By doing this, some mode preferences can be already noticed. Note however that in this part of the analysis, the effects of the variation of attributes among transport modes are not considered. In Fig. 3 an outline of the preferences exhibited for the egress mode choice is presented. We observe a clear tendency towards walking and bus/tram. Nevertheless, shared micromobility accounts for a quarter of all choices, suggesting potential of these modes to cover the last-mile of multimodal trips with metro as the main mode.

In Fig. 4 an outline of the preferences exhibited for the complete trip mode choice is presented. Half of the choices are for privately owned vehicles (*i.e. car and bicycle*), whereas the other half is distributed between metro combinations and shared e-moped. It strikes as interesting the high share of metro choices, especially considering the rather low proportion of frequent transit travellers within the sample. Besides, by being chosen almost once for every ten tasks, shared e-mopeds seem to be a viable alternative as main (in this case only) mode for trips long enough to compete with car and metro, and not only for short trips (including access and egress to and from public transport). Note that the distribution of egress modes when metro is chosen varies compared to

Table 7
Sample composition – Comparison with Rotterdam population (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%	–

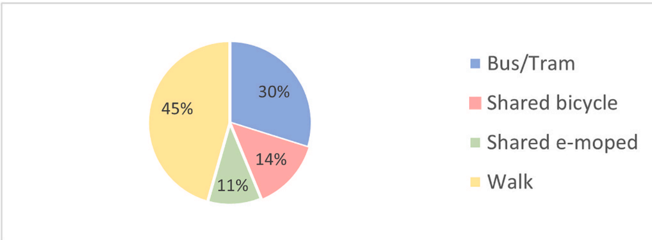

Fig. 3. Choice overview – egress mode choice.

the overall distribution presented in Fig. 3. According to the results, for respondents who tend to choose to travel by metro, the preferred egress mode is also public transport, namely bus or tram. On the other hand, people who would prefer walking the last mile, tend to select metro less frequently. Furthermore, the proportion of shared micromobility as egress alternatives decreases compared to the overall distribution. The latter could be influenced by potential strong preferences towards transit of some respondents ('public transport lovers').

3.2. Multinomial logit model (MNL)

In total 25 MNL models are estimated: 1 multinomial base model, and 24 MNL models with interaction effects. Firstly, we define the base MNL model, which is then used to carry out the interaction models, between eight socio-demographic variables and three taste parameters (ASC, travel cost and travel time). Each interaction is studied independently, resulting in a total of 24 interaction models.

3.2.1. Base MNL

Table 8 presents the results of the MNL base model. Given the multimodal nature of metro alternatives, a column is added with their total ASC (sum of metro and egress). Most parameters are statistically significant on a 99% confidence interval. The only parameter not significant is metro waiting time. This indicates that waiting for the metro might not play a role in mode choice in the context of this study. Focusing only on the ASC parameters, we observe that on average, the car remains the most attractive option for users, yet bicycles and the combination metro and bus/tram seem to have similarly positive perceptions. Among the alternatives including shared micromobility, shared e-moped as an individual mode appears as the one with the better perception. Concerning cost, people seem to be considerably more sensitive to egress cost than to main mode cost (almost five times). Contrastingly, in terms of in-vehicle time, 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 is perceived almost twice as negatively as in-vehicle time.

3.2.2. MNL with interaction effects

In terms of socio-demographics, higher modal fit indicators are found when analysing interaction effects with ASC parameters, instead of with the time or cost parameters. This might suggest that socio-demographic characteristics affect to a greater extent the base perception of modes, rather than the sensitivity to 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. Concerning age effects, we found that the younger the group, the higher the base preference toward shared alternatives. In general, the older the age group the further ASC values estimated are from ASC for car, which is fixed to zero. This might suggest that base preferences towards modes play a more relevant role for old groups than for younger groups.

Regarding the frequency of use of public transport, more frequent travellers have a better perception of the metro regardless of cost and time attributes. The same holds for bus/tram as an 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 the perception of shared micromobility is positively affected by the frequency of use of public transport.

From the other models, some interesting findings are worth mentioning. For instance, men seem to dislike metro and shared bicycles

Table 8
Parameter estimates – MNL base model.

Name	Description	Value	Total alternative	Rob. *t*-test
Alternative specific constants				
ASC_METRO	Alt. Specific constant - Metro	−0.865		−5.59[a]
ASC_BT	Alt. Specific constant - bus/tram	0.683	*−0.182*	7.24[a]
ASC_SB	Alt. Specific constant - shared bycicle as egress	−0.856	*−1.721*	−8.62[a]
ASC_SM_E	Alt. Specific constant - shared e-moped as egress	−0.934	*−1.799*	−7.69[a]
ASC_WALK	Alt. Specific constant - Walk	0.007		0.04
ASC_SM	Alt. Specific constant - shared e-moped as main mode	−1.380		−17[a]
ASC_BIKE	Alt. Specific constant - private bicycle	−0.275		−2.57[b]
ASC_CAR	Alt. Specific constant - Car (Base alternative)	0.000		–
Cost parameters				
B_MAIN_COST	Parameter - Main mode cost	−0.093		−8.68[a]
B_EGRESS_COST	Parameter - Egress cost	−0.425		−5.37[a]
Time parameters				
B_MAIN_TIME	Parameter - Main mode searching time	−0.034		−6.64[a]
B_EGRESS_TIME	Parameter - Egress time	−0.039		−3.25[a]
B_METRO_WAIT	Parameter - Main mode travel time	−0.014		−0.65
B_WALK	Parameter - Walking time	−0.064		−6.29[a]

[a] Parameter significant at a 99% confidence interval.
[b] Parameter significant at a 95% confidence interval.

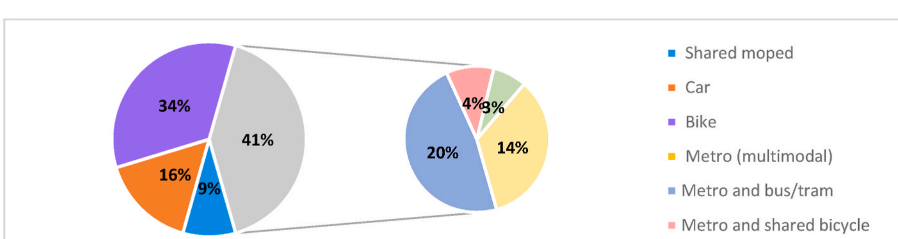

Fig. 4. Choice overview – Complete trip mode choice.

more than women, yet they seem to have a better perception of shared e-mopeds. In addition, being familiar with shared micromobility positively affects the preference for these modes. The latter is considered important, as it highlights the importance of encouraging travellers to experience the use of 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. Finally, the inclusion of trip purpose effects does not cause great improvements in modal fit for any of the three estimated models.

3.3. Mixed logit models (ML)

In general ML models yield considerably better modal fit indicators than MNL models. It might be an indicator of the relevance of nesting of alternatives and variation of preferences across the population. Two effects are modelled: nesting of alternatives and taste heterogeneity. As the tastes for both the attributes and mode-specific constants are expected to vary across the population, the evaluation of taste heterogeneity is performed for both types of parameters. The best fitting ML model according to Rho square evaluation is the ML model that captures preference heterogeneity. Hence, complete results for said model are presented and discussed in detail in this paper (see Table 9).

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. In this case, 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.

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 for one (or more) modes over that of the car. To better visualize the variation of ASC, see Fig. 5. Note that all parameters are rather widely distributed, which suggests high variation in the perception towards different modes across the population. Some of this variation might be explained by the effects of socio-demographic and transport-related characteristics. Note that the mean ASC_BT is not statistically significant. It is kept in the model as its standard deviation is both different to zero and statistically significant at a 99% confidence interval.

Regarding taste heterogeneity for attributes, cost parameters are found to be rather widely distributed across the population. In other words, while for some people the cost of the trip is a very relevant

Table 9
Model results – ML to capture ASC heterogeneity.

Parameter	Value	Sigma	Rob. *t*-test parameter	Rob. *t*-test sigma
ASC_BIKE	−0.561	3.02	−1.97[b]	12.2[a]
ASC_BT	0.373	2.36	1.03	13.8[a]
ASC_METRO	−1.07	2.37	−3.15[a]	14.1[a]
ASC_SB	−1.89	−2.09	−4.43[a]	−11.4[a]
ASC_SM	−1.7	0	−8.43[a]	–
ASC_SM_E	−2.19	−2.36	−4.39[a]	−8.27[a]
ASC_CAR	0	2.45	–	12.4[a]
B_EGRESS_COST	−0.715		−6.37[a]	
B_EGRESS_TIME	−0.073		−4.4[a]	
B_MAIN_COST	−0.186		−9.74[a]	
B_MAIN_TIME	−0.071		−8.85[a]	
B_METRO_WAIT	−0.031		−0.947	
B_WALK	−0.11		−7.98[a]	

[a] Parameter significant at a 99% confidence interval.
[b] Parameter significant at a 95% confidence interval.

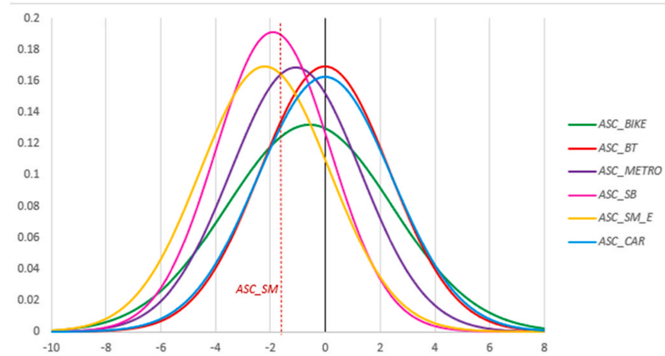

Fig. 5. ASC parameters distribution.

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 has also a fairly wide distribution. Concerning other time parameters, the distribution of the taste for travel time in the main mode is rather tight. The latter might suggest that sensitivity for this characteristic of a trip does not seem to vary considerably amongst respondents. Contrastingly, the egress time parameter stands out as the one more broadly distributed.

Finally, from the model for nesting effects, we found five significant nests at a 99% confidence interval: bicycle alternatives, metro alternatives, private modes, egress with shared micromobility, and shared e-moped alternatives. In other words, the results 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. Among all the alternatives, the *metro + shared bicycle* and *metro + shared e-moped* alternatives have the highest correlation.

4. Conclusion

This paper studies choices related to shared micromobility in the context of an integrated multimodal network. It responds to the need of understanding the relationship between transit and shared micromobility. Although the body of research insights in this domain is growing, mode choice in a multimodal network with integrated services, including competition and complement between these modes is still to be studied more in detail. According to the results, shared micromobility seems to be an appealing alternative as an egress mode for metro trips. Despite not being the overall preferred option, the 25% of choices towards shared micromobility in the case study suggest that they represent interesting alternatives for users. In this study, and specifically in the survey walking is always presented as a viable option. In this case, it results in a strong preference for this option as an egress alternative. Besides, shared e-mopeds proved to be an interesting alternative as an individual mode for long-distance trips. The findings support the idea of complementarianism between shared micromobility and public transport found in the literature, but also the notion of them being simultaneously competition. Considering that satisfaction with public transport is affected by the whole door-to-door trip (Susilo & Cats, 2014), these findings might suggest a positive influence of shared micromobility on preference towards transit services. It is important to highlight that in real-life situations, 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 micromobility to increase.

Characteristics proper of each mode different to time and cost showed to be highly relevant 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 captures all the unobserved preferences towards the different alternatives, not captured by the included parameters. Accordingly, they might reflect the importance of factors not included in the model such as comfort, ease of use, and flexibility, among others. The results show that most negative perceptions are for the multimodal alternatives composed of metro and shared micromobility. The latter suggests that if time and cost characteristics of transport alternatives are not considered/equal, 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 micromobility 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, based only on ASC the choice probability for alternatives including shared micromobility still adds up to around 17% according to the MNL model. It can be argued to indicate that there is room for shared micromobility in the mobility landscape, both as individual modes for the whole trip and as egress options for public transport trips.

In addition to base mode preferences, five other aspects appear as important determinants of choices under the assumed conditions: total travel time, egress cost, having used shared micromobility before, frequency of use of public transport, and age. Regarding the first two, two things seem important to be highlighted. First, according to the results, in multimodal trips, the egress leg does not seem to be perceived more negatively in terms of travel time than the main leg. Nonetheless, in terms of travel costs, the magnitude of the parameters suggests an important difference in the way travellers perceive costs on both trip legs. The cost on the egress leg is weighted more heavily than the cost on the main leg. For shared bicycles and shared e-mopeds as egress modes, it might suggest that they can benefit from offering travel time savings and from causing a decrease in walking distances. In other words, travellers seem to be willing to travel longer in their 'last-mile', if it results in shorter overall travel times. However, prices of egress alternatives need to be determined carefully so as not to be a strong deterrent against their use. Besides, the results of this study suggest a clear positive attitude towards shared micromobility of those who have used it before. Accordingly, it seems reasonable to think that encouraging a first experience with it can positively influence the overall perception of users towards these modes. Applied to the case of first/last mile trips, campaigns or pilots in public transport hubs that encourage users to try shared micromobility might help to improve the general perception of people towards these transport modes.

Concerning the frequency of use of public transport, we found that it has an important influence on the perception of users towards the different modes. The preference for shared micromobility 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. (2022) 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 positively affects 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 a positive attitude towards shared micromobility has already been observed.

With respect to socio-demographic factors, age seems to be the most influential, especially concerning base preferences towards the different modes. Age showed to be a good indicator of preference towards the car, with the relative preference for the car increasing with age. It holds for both shared bicycles and shared e-mopeds as egress modes, for which it seems that the younger the traveller, the more likely to use shared micromobility for the last-mile. The latter could be seen as an indicator of a potential group to target if collaborations schemes are to be designed.

Finally, despite the value of this work in understanding mode choice related to shared micromobility, many things are yet to be studied. For instance, the extent to which shared micromobility might help to enhance coverage of public transport, and how that can affect mode choice. 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 micromobility. 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. Besides, it seems relevant to understand to what extent each assumed characteristic of the integration affects the relationship between public transport and shared micromobility, as well as the overall role of the latter in the mobility market. In that sense, it is advised to study the real effect of availability of shared micromobility 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.

CRediT authorship contribution statement

Alejandro Montes: Conceptualization, Methodology, Writing – review & editing. **Nejc Geržinic:** Conceptualization, Methodology, Writing – review & editing. **Wijnand Veeneman:** Supervision. **Niels van Oort:** Conceptualization, Methodology, Writing – review & editing. **Serge Hoogendoorn:** Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

9292 2021 9292. (2021). 9292 Reist met je mee!. https://9292.nl.
About – Google Maps.(2021). https://www.google.com/maps/about/#!/.
Arentze, T. A., & Molin, E. J. E. (2013). Travelers' preferences in multimodal networks: Design and results of a comprehensive series of choice experiments. *Transportation Research Part A: Policy and Practice, 58*, 15–28. https://doi.org/10.1016/j.tra.2013.10.005
Ben-Akiva, M., & Bierlaire, M. (2000). Discrete choice methods and their applications to short term travel decisions. *Handbook of Transportation Science, 26*. https://doi.org/10.1007/978-1-4615-5203-1_2
Bierlaire, M. (2020). *A short introduction to PandasBiogeme (TRANSP-OR 200605; series on biogeme*. Ecole Polytechnique Fédérale de Lausanne (transp-or.epfl.ch).
Bocker, L., Anderson, E., Uteng, T. P., & Throndsen, T. (2020). Bike sharing use in conjunction to public transport: Exploring spatiotemporal, age and gender dimensions in Oslo, Norway. *Transportation Research Part A: Policy and Practice, 138*, 389–401. https://doi.org/10.1016/j.tra.2020.06.009
Centraal Bureau voor de Statistiek. (2021). *Inwoners per gemeente [Webpagina]*. Centraal Bureau voor de Statistiek. https://www.cbs.nl/nl-nl/visualisaties/dashboard-bevolking/regionaal/inwoners.
Check. (2021). *Check*. https://ridecheck.app/.
Choicemetrics. (2018). *Ngene user manual*.
Donkey Republic. (n.d.). Never be without a bike-donkey Republic. Donkey Republic - every Ride counts. Retrieved September 12, 2021, from https://www.donkey.bike/felyx-Beat the streets. (2021). Felyx. https://felyx.com/.
Ferrero, F., Perboli, G., Rosano, M., & Vesco, A. (2018). Car-sharing services: An annotated review. *Sustainable Cities and Society, 37*, 501–518. https://doi.org/10.1016/j.scs.2017.09.020
Geržinič, N., Cats, O., van Oort, N., Hoogendoorn-Lanser, S., & Hoogendoorn, S. (2023). What is the market potential for on-demand services as a train station access mode? *Transportmetrica: Transportation Science*.
GO Sharing. (2021). *GO Sharing | A green planet with mobility for everyone. Go-Sharing. Com*. https://nl.go-sharing.com/en/.
Hardt, C., & Bogenberger, K. (2019). Usage of e-scooters in urban environments. *Transportation Research Procedia, 37*, 155–162. https://doi.org/10.1016/j.trpro.2018.12.178
Ji, Y., Ma, X., Yang, M., Jin, Y., & Gao, L. (2018). Exploring spatially varying influences on metro-bikeshare transfer: A geographically weighted Poisson regression approach. *Sustainability, 10*(5), 1526. https://doi.org/10.3390/su10051526

van Kuijk, R. J., de Almeida Correia, G. H., van Oort, N., & van Arem, B. (2022). Preferences for first and last mile shared mobility between stops and activity locations: A case study of local public transport users in utrecht, The Netherlands. *Transportation Research Part A: Policy and Practice, 166*, 285–306.

Leth, U., Shibayama, T., & Brezina, T. (2017). Competition or supplement? Tracing the relationship of public transport and bike-sharing in vienna. *GI_Forum, 1*, 137–151. https://doi.org/10.1553/giscience2017_02_s137

Machado, C., de Salles Hue, N., Berssaneti, F., & Quintanilha, J. (2018). An overview of shared mobility. *Sustainability, 10*(12), 4342. https://doi.org/10.3390/su10124342

Ma, X., Yuan, Y., Van Oort, N., & Hoogendoorn, S. (2020). Bike-sharing systems' impact on modal shift: A case study in delft, The Netherlands. *Journal of Cleaner Production, 259*, Article 120846. https://doi.org/10.1016/j.jclepro.2020.120846

McLeod, S., Scheurer, J., & Curtis, C. (2017). Urban public transport: Planning principles and emerging practice. *Journal of Planning Literature, 32*(3), 223–239. https://doi.org/10.1177/0885412217693570

Meng, L., Somenahalli, S., & Berry, S. (2020). Policy implementation of multi-modal (shared) mobility: Review of a supply-demand value proposition canvas. *Transport Reviews, 40*(5), 670–684. https://doi.org/10.1080/01441647.2020.1758237

van Mil, J. F. P., Leferink, T. S., Annema, J. A., & van Oort, N. (2020). Insights into factors affecting the combined bicycle-transit mode. *Public Transport*. https://doi.org/10.1007/s12469-020-00240-2

Mobike. (2021). *Mobike | smart bike share*. https://mobike.com/global/.

Oeschger, G., Carroll, P., & Caulfield, B. (2020). Micromobility and public transport integration: The current state of knowledge. *Transportation Research Part D: Transport and Environment, 89*, Article 102628. https://doi.org/10.1016/j.trd.2020.102628

Optimaal OV - RET. (2021). https://corporate.ret.nl/mvo/optimaal-ov.

Otero, I., Nieuwenhuijsen, M. J., & Rojas-Rueda, D. (2018). Health impacts of bike sharing systems in Europe. *Environment International, 115*, 387–394. https://doi.org/10.1016/j.envint.2018.04.014

OV-fiets. (2021). *Public transport bicycle l Rent a bicycle for the last part of your journey | NS*. https://www.ns.nl/deur-tot-deur/ov-fiets.

Shaheen, S. (2016). *Mobility and the sharing economy: Potential to overcome first- and last-mile public transit connections*. https://doi.org/10.7922/G2862DN3

Susilo, Y. O., & Cats, O. (2014). Exploring key determinants of travel satisfaction for multi-modal trips by different traveler groups. *Transportation Research Part A: Policy and Practice, 67*, 366–380. https://doi.org/10.1016/j.tra.2014.08.002

Torabi, F., Araghi, Y., van Oort, N., & Hoogendoorn, S. P. (2022). Passengers preferences for using emerging modes as first/last mile transport to and from a multimodal hub case study Delft Campus railway station. *Case Studies on Transport Policy, 10*(1), 300–314.

Train, K. (2002). *Discrete choice methods with simulation*. Cambridge University Press.

Van Marsbergen, A., Ton, D., Nijenstein, S., Annema, J. A., & van Oort, N. (2022). Exploring the role of bicycle sharing programs in relation to urban transit. *Case Studies on Transport Policy, 10*, 1.

Walker, J. L., Wang, Y., Thorhauge, M., & Ben-Akiva, M. (2018). D-Efficient or deficient? A robustness analysis of stated choice experimental designs. *Theory and Decision, 84*(2), 215–238. https://doi.org/10.1007/s11238-017-9647-3

Yan, Q., Gao, K., Sun, L., & Shao, M. (2020). Spatio-temporal usage patterns of dockless bike-sharing service linking to a metro station: A case study in shanghai, China. *Sustainability, 12*(3), 851. https://doi.org/10.3390/su12030851

Zhang, Y., & Zhang, Y. (2018). Associations between public transit usage and bikesharing behaviors in the United States. *Sustainability, 10*(6), 1868. https://doi.org/10.3390/su10061868