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MASTER'S THESIS

Exploring Preferences for Transportation Modes in an Urban Air Mobility Environment: a Munich Case Study

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Abstract

Urban Air Mobility (UAM) is a recent concept proposed for solving the urban mobility problem, such as urban traffic pollution, congestion and noises. Before introducing UAM to the market, demand could be evaluated by understanding the potential users' choice behaviour regarding current existing urban transportation modes and new autonomous transportation services, in a hypothetical UAM environment. This research intends to gain insight into the travel behaviour impacts of autonomous transportation modes and notably, UAM, by deriving measures for transportation service attributes and by identifying the characteristics of potential users who are likely to adopt the autonomous transportation services, particularly the services of UAM.

For this purpose, a stated preference survey including a stated choice experiment was designed and conducted. A main mode choice multinomial logit (MNL) model and several sub-models based on the profiles of the respondents were developed, regarding four transportation alternatives, namely private car, public transportation (PT), autonomous taxi (AT) and autonomous flying taxi (AFT).

The results indicate that travel time, travel cost and safety may be critical determinants of the adoption of the autonomous transportation modes. Moreover, the respondents having relatively higher value of time (VOT) may be willing to pay more for using autonomous transportation modes, especially the service of UAM. The results also suggest that younger-aged individuals and older-aged individuals with high income may be more likely to accept the service of UAM. In addition, the impact of trip purpose on the adoption of UAM was also revealed through the examination of the survey results and the model analysis.

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List of Abbreviations

AV	Autonomous Vehicle
AT	Autonomous Taxi
AFT	Autonomous Flying Taxi
AIC	Akaike Information Criterion
ASC	Alternative-Specific Constant
BIC	Bayesian Information Criterion
eVTOL	Electric Vertical Take-off and Landing Aircraft
EIB	European Investment Bank
IIA	Independence of Irrelevant Alternatives
IID	Independent and Identically Distributed Terms
ML	Mixed Logit
MNL	Multinomial Logit
MVV	Münchner Verkehrs- und Tarifverbund
NL	Nested Logit
ODM	On Demand Mobility
PT	Public Transportation
RP	Revealed Preference
RUM	Random Utility Model
SP	Stated Preference
SC	Stated Choice
SAV	Shared Autonomous Vehicle
UAM	Urban Air Mobility

VOT	Value of Time
VTOL	Vertical Take-off and Landing Aircraft
WTP	Willingness to Pay

1 Introduction

Rapid population growth and urbanisation have imposed enormous strains not only on the environment but also urban transport. There is an unexpected increase in the scarcity of many resources, not only oil, but also physical space (Zetsche, 2017). According to Angel, Parent, Civco, & Blei (2011), the number of people living in cities is double from 2011 to 2054 while the urban land cover is expected to have doubled by 2030 due to decreasing city densities (persons per hectare). However, at the same time, the mobility requirement is increasing. Consumers will opt for the form of transportation which is faster, cheaper, cleaner, and safer than today (Corwin, Jameson, Pankratz, & Willigmann, 2016). This tendency will drive the contemporary transport system to its limits. Therefore, new transport solutions must be developed to fulfil future mobility needs.

The recent rapid technological development of self-driving cars led to the current situation in which tests with driver-less cars are performed all over the world. With increasing autonomous driving assistance systems in car production, the shift towards a fully autonomous driving experience has already begun (Hörl, Ciari, & Axhausen, 2016). Moreover, as a strong force with the potential to drastically change the way we see mobility, the autonomous technology nowadays even can make travellers' dreams a reality by letting them fly over traffic jams during rush hours. Not only aircraft manufacturers but also start-ups, technological companies, and automobile manufacturers see great potential in sky-bound autonomous transport technology. A novel concept (Holden & Goel, 2016; Airbus, 2018) called Urban Air Mobility (UAM) is proposed by introducing next-generation vertical take-off and landing aircraft (VTOL) as a transport service, which can add a new dimension to the urban transport system. This new transport mode is designed to be capable of performing passenger transport missions in an urban environment and giving people back time lost in daily travel (Holden & Goel, 2016).

Another trend of future mobility is the higher degree of shared vehicle ownership. The emergence of *sharing economy* encourages consumers to rely upon mobility provided as a service rather than personal vehicle ownership, and, thus, significantly reduce costs by splitting the expense of asset ownership among multiple individuals or placing the burden of ownership on service providers (Vascik & Hansman, 2017). Meanwhile, the recent advancements in communication capabilities and the proliferation of smartphones has facilitated the development of On Demand Mobility (ODM), which allows the point-to-point transportation within a short period of travel using an alternative transportation option rather than consumers' private vehicles (Vascik & Hansman, 2017).

The convergence of the autonomous technology and the *sharing trend* can form the new term *shared autonomous mobility*. Corwin et al. (2016) anticipated that as a new state of future transport — *a new age of autonomy*, which will likely happen quicker and more dramatically in the urban environment. Significant change will begin soon, and the market for personal mobility could transform radically over the next 25 years if shared and autonomous transportation services are adopted as quickly as other technologies such as smartphones and the Internet (Corwin et al., 2016).

1.1 Research Motivation

Before introducing VTOLs and UAM to the market, evaluating the demand drivers is a prerequisite (Straubinger & Rothfeld, 2018). To predict the potential demand, understanding people's choice behaviour regarding several current existing urban transportation modes and new transport services is highly essential. Moreover, to see how the novel transportation modes will be integrated with the current existing transportation system, analysing choice behaviour concerning transportation modes provides input to develop a comprehensive urban mobility model which aims at understanding the operational environment of novel transport modes.

Meanwhile, from the research methodology perspective, there currently exist only a handful of transportation-related choice behaviour studies, which predict the adoption of autonomous vehicles or shared autonomous taxis (Haboucha et al., 2017; Bansal et al., 2016; Krueger et al., 2016) and modelling choice behaviour in relation to discrete choice experiment (Beck et al., 2016). Furthermore, it is a remarkable fact that, to the best of the author's knowledge, no current research exists to analyse the potential behaviour shifts and the underlying motivations to use UAM, using discrete choice modelling methodology.

Therefore, it leads to the conclusion that there can be an adequate behaviour model for analysing user preference for conventional and novel transportation modes, and the acceptance of UAM is of particular interest.

1.2 Objectives and Research Problems

The adoption of autonomous transportation modes may provide benefits to society, but also entail risks (Krueger et al., 2016). For the design of effective policies which aims at realising the advantages of future autonomous transportation modes, it may be helpful to gain insight into how transportation mode choice will be performed in a hypothetical UAM environment, where autonomous vehicle is also involved as a transportation alternative, together with the other conventional transportation modes.

Given the need mentioned above, the following objective is formulated:

Using discrete choice modelling methodology to quantitatively estimate the independent influence of service attributes on the adoption of UAM, and identify the potential users who are likely to adopt the services of UAM, considering other conventional and non-conventional (autonomous) transportation systems.

In working toward the objective, the following research problems are pursued:

1. How can an experiment be adequately designed to collect mode choice data for situations where the conventional and non-conventional transport modes are included as individual transport alternatives?
2. What are the transportation service attributes which may potentially affect the preference for given transportation alternatives, notably the adoption of UAM?
3. What are the characteristics of the potential users who are likely to adopt the autonomous transportation services, particularly the services of UAM?

1.3 Research Framework

The thesis consists of five main sections, including Problem Definition, Methodology, Results, Discussion, and Conclusion. A framework was developed to present the research structure systematically, as shown in Figure 1.1.

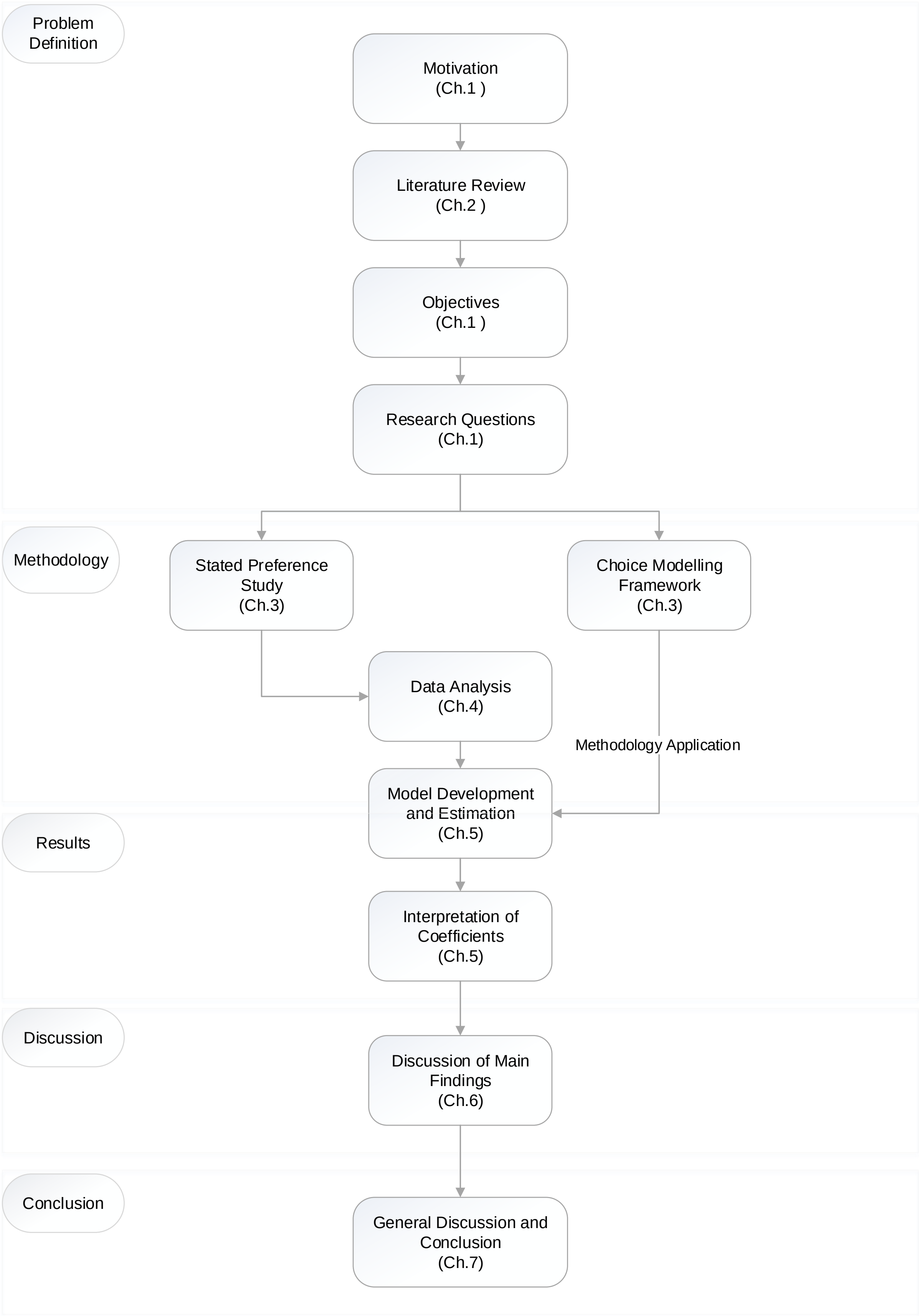


Figure 1.1 Research Framework

1.4 Expected Contributions

The thesis is expected to contribute potentially to the following areas:

Expected methodological contributions:

a) Behaviour modelling. A Stated Preference experiment was conducted for understanding the future transport mode choice behaviour when several non-conventional transport modes are involved as alternatives. The qualitative choice attribute was proposed to be integrated to investigate the mode choice decisions.
b) Further model development. The survey result, as well as the modelling output, are to be considered as input for further development of an urban mobility model that can integrate and enable evaluations of novel urban transportation concepts and their operational setup.
c) Future work. Potential research limitation and future research directions were identified, contributing indirectly to the growing body of research on this topic.

Expected practical contributions:

a) For manufacturers and operators, the analysis result may help gain insight regarding potential market penetration rate of UAM.
b) For manufacturers and regulatory authorities, several policy implications inferred from the model results may contribute to the policy-making and relevant regulation formulation.

2 Literature Review

This chapter goes through previous research carried out in four main areas, including the status quo of autonomous mobility services and market feasibility barriers, transportation mode choice research, choice modelling and stated choice methods. A thorough review of the findings and research methodology applied in transportation mode choice research is presented in Section 2.2. Considering the main research objective of this thesis, the findings of current existing studies regarding autonomous vehicles, shared autonomous vehicles and autonomous flying vehicles have been given particular attention. Section 2.3 provides a comprehensive review of the choice modelling with a particular focus on the theory behind the methods used in this research. An overview of fundamental principles of stated choice survey design method is given in Section 2.4.

2.1 Autonomous Mobility Services and Market Feasibility Barriers

New technologies enable the rapid development of autonomous technology. On the software side, tremendous advances have been made in artificial intelligence, sensor fusion, machine learning and big data. On the hardware side, communication and sensor technology give rise to the development of vehicle-to-vehicle and vehicle-to-infrastructure technology. Hörl et al. (2016) found that the current existing literature agrees that fully autonomous cars are to appear within the next decade and that a large number of fully autonomous vehicles will be on the road within the next 50 years. While autonomous cars will not directly enable autonomous aircraft, their constituent technologies have a strong commonality (Holden & Goel, 2016).

However, a significant challenge of current research is to develop coherent scenarios of an *autonomous future* based on predictions (Hörl et al., 2016). The main challenges of bringing the autonomous mobility services to the market can be defined from the following aspects: technology, regulation, infrastructure, and user behaviour.

This section contains two subsections regarding autonomous vehicle service and UAM service. An overview of social and environmental impact concerning each type of service is given firstly, followed by a brief description of the services provided by the autonomous transportation modes and the relation to other transportation modes. At last, particular emphasis is placed on the summary of potential market entry barriers.

Autonomous Vehicle

The introduction of autonomous cars promises to solve many problems for today's travellers, who operate vehicles in often unpleasant and tiring traffic situations (Becker & Axhausen, 2017). The current discussion on the scenarios highlights several aspects where autonomous driving may offer several advantages that may be relevant to mode choice, such as comfort, possibility to use the Autonomous Vehicles (AVs) without a driver's license (Heinrichs & Cyganski, 2015), and the possibility to pursue useful activities while travelling (Litman, 2014). Nevertheless, there is a contradictory effect existing among the increase in traffic capacity due to better traffic flow, reduced crashes, redeveloped infrastructure, and induced demand caused by the introduction of the new transport mode (Hörl et al., 2016). Research shows that AVs are expected to be most efficient in urban areas with dense traffic demand (Bischoff & Maciejewski, 2016).

Looking at the environmental effects of AVs, it can be said that they are generally regarded as a positive development concerning emissions reduction and energy saving (Hörl et al., 2016). However, Thomopoulos & Givoni (2015) stated that positive effects would only become apparent if AVs are used in a shared manner.

In this thesis, the term AV refers to the electric-powered ground-based Shared Autonomous Vehicle (SAV)[1](fully autonomous), specifically in the form of Autonomous Taxi[2] or Driverless Taxi, as defined by Fagnant, Kockelman, & Bansal (2015), which could provide relatively inexpensive mobility ODM services.

When using the on-demand service, the trip could be, e.g. reserved via smartphone app upfront for the desired time. The AT could pick up and drop off from/to users' origins/destinations, while the user would have access to up-to-date information on the location of the vehicle and the expected arrival time. Similar to the capacity of a regular taxi, the AT could carry up to five passengers, and the user would never share the vehicle with people who are not in the group he or she is travelling with (number of people has no impact on the price). During the trip, the vehicle is driving automatically and with the same speed as for conventional cars. Once arrived at a destination, the user simply pays per ride, and there is no need to search for a parking spot. (Winter, Oded, Martens, & van Arem, 2017)

[1] SAVs merge the paradigms of short-term car rentals (as used with car-sharing programs like Car2Go and ZipCar) and taxi services (Fagnant et al., 2015).
[2] The abbreviation AT is used in the following text and the survey.

In terms of the relation of ATs to other modes, on the one hand, ATs could offer convenient last-mile solutions and provide services on less frequently used routes, while on the other hand, ATs could potentially compete with public and private transportation. Comparing with public transportation modes (PT), ATs offer more privacy and intimacy, seating availability would be guaranteed and walking times would be significantly reduced (Krueger et al., 2016). When comparing with travelling by private cars, AT users could gain a similar level of flexibility but would not have to interact with the vehicle, which would allow users to pursue relaxing or productive activities while travelling (Krueger et al., 2016). However, for high-frequency AT users, one restriction is the relatively higher travel cost.

Figure 2.1 Illustration of Autonomous Taxi (iReviews, 2017)

According to Hörl et al. (2016), while the technology development of AVs seems to be swiftly progressing, the adoption process is just beginning. Regarding the challenges of adopting AVs, except some technological restrictions such as comparably slow progress in battery technology development and safety level improvement, some additional barriers need to be overcome until AVs become an integrated part of everyday life (Hörl et al. 2016). One of the major challenges is the legal issue, concerning who will take responsibility if a property is damaged or people are hurt. Another limiting factor is urban infrastructure. The existing infrastructure and investments in infrastructure will have a substantial impact on how AVs will be used in the future. Last but not least, the motivation of people to engage in autonomous mobility is another crucial aspect. According to Hörl et al. (2016), as long as conventional traffic is the majority in the road, behavioural aspects are expected to have an inhibiting effect on the adoption.

Urban Air Mobility and Autonomous Flying Vehicle

The challenges caused by population growth and urbanisation leads to changes, not only in transport demand but also in infrastructure requirements and average travel distances. According to Airbus (2018), the novel concept, UAM, was formed with the target of enabling a world where people or goods can be transported around densely populated cityscapes within minutes, on demand. UAM could be realised in the form of air taxis and shared or owned connected commuter vehicles picking up passengers on request as part of an on-demand urban network (Airbus, 2018). Currently, a lot of research regarding various types of passenger flying vehicles is being conducted on the manufacturer's side (see, e.g. A[3], 2018; Joby Aviation, 2018; Volocopter GmbH, 2018; Lilium GmbH, 2018; Ehang, 2018). Based on the research concerning the future of mobility done by Lineberger, Hussain, Mehra, & Pankratz (2018), a passenger drone is expected to be an electric or hybrid-electric quadcopter that can be used to move people or cargo between established and on-demand origination and destination. The vehicles can be manually piloted, remotely piloted, or be fully autonomous, and they could cover short to medium-range distances (Lineberger et al., 2018). Today, many companies are focusing on electric or hybrid-electric VTOL vehicles (eVTOLs), which is an aircraft that can take off, hovers and land vertically and do not require runways (Lineberger et al., 2018).

According to Holden & Goel (2016), UAM will add the third dimension, which increases the accessibility between suburbs and cities and, ultimately within urban areas. The autonomous VTOLs are expected to operate at up to five times the speed of the average conventional ground vehicles. Moreover, autonomous VTOLs are fuelled by electricity and are expected to be energy efficient (Airbus, 2018). It is operated with zero operational emissions and is substantially quieter than a traditional helicopter (Lineberger et al., 2018).

In order to avoid possible confusion, the specific case of fully autonomous eVTOL (Autonomous Flying Taxi[3]) is used as an example in this thesis. The air vehicle is envisioned to be used as a cost-comparable alternative for short-range (10 km to 50 km) urban transportation like cars or PT but providing air-based ODM services (Aurora Flight Sciences, 2018; Volocopter GmbH, 2018; Ehang, 2018). Different from the usage of ATs, AFTs have to be called to the vertiports which are expected to be distributed throughout a city. The air vehicle can carry up to four passengers (the travel group the user is travelling with) and enable passengers to significantly reduce the in-vehicle travel times while gaining comfortable travelling

[3] The abbreviation AFT is used in the following text and in the survey.

experience as well as multitasking possibilities. Nevertheless, regarding the travel cost, the high-frequency users might spend even more than travelling with AT.

Figure 2.2 Illustration of Autonomous Flying Taxi (Lilium GmbH, 2018)

Despite the technological progress and potential applications of eVTOL aircraft, several critical aspects of barriers need to be considered to bring the on-demand UAM to the market (Holden & Goel, 2016). First of all, more advanced technologies are required to improve sensing and recognition capabilities, detect-and-avoid capabilities, as well as energy management (Lineberger et al., 2018). From the regulation and air traffic management perspectives, new regulations and new air traffic control system for fully autonomous eVTOL operations are needed, with issues around how to allocate the use of the airspace considering the increasing number of flying vehicles utilising the airspace (Lineberger et al., 2018). The greatest operational barrier to deploy eVTOL fleets in urban areas is a lack of sufficient locations to place take-off and landing zones, parking lots, charging stations, and vertiports (Holden & Goel, 2016). All the infrastructure development would require the collaboration of commercial stakeholders and the local planning authorities (Lineberger et al., 2018). Apart from the above considerations, potential passengers also need to overcome psychological barriers of using autonomous aircraft. According to the survey done by UBS, a Swiss global financial services company, 54 percent of the respondents said that they were unlikely to take a pilotless flight (Castle et al., 2017). Therefore, safety is playing a crucial role, as any failure can draw significant attention and can slow the pace of adoption. Manufacturers and regulatory authorities need to demonstrate a near-flawless safety record, covering both mechanical integrity and safe operations (Lineberger et al., 2018).

This thesis sets analysing choice behaviours from user adoption perspective as a starting point, providing policymakers essential insights into decision making concerning encouraging the use of autonomous mobility services.

2.2 Transportation Mode Choice Research Review

Since UAM and autonomous flying vehicles are a novel phenomenon, current research concerning it focus on technological and operational aspects (such as Holden & Goel, 2016; Parker, 2017; Schuchardt et al., 2015). However, no mode choice model analysing the potential user preference among conventional transport modes, AVs, and autonomous flying vehicles has been found. Therefore, various alternative sources were examined to determine significant factors which might influence the potential behaviour shifts and the adoption of the new autonomous flying mode. The perspectives discussed in this section are based on general literature review of factors affecting transport mode choice, review of a handful current existing studies that have used discrete choice theory to model various aspects of AVs and SAVs, and review of few studies about public opinions regarding AVs and flying vehicles.

According to the reviewed sources mentioned above, and considering Becker & Axhausen (2017) in their comprehensive review of surveys investigating the adoption of autonomous vehicles, the explanatory variables are categorised into three groups: the transportation-related variables, individual-specific variables, and attitudinal/psychological variables.

2.2.1 Transportation-Related Variables

Based on the general literature review of transport mode choice studies concerning conventional transport modes (e.g. Fillone, 2007; Wardman, 2009; Richter & Keuchel, 2012; Atasoy, Glerum, & Bierlaire, 2006; Vrtic, Schuessler, Erath, & Axhausen, 2009), it is concluded that the most common transportation-related factors include travel cost and travel time. In some works, the cost and time attributes are modes specified. For example, Vrtic, Schuessler, Erath, & Axhausen (2009) included not only the travel cost for the private car but also fuel cost, parking cost and toll, while for public transit modes, departure time is a significant time attribute other than travel time. Moreover, variables such as headway, number of transfers, access time, and waiting time have also been found to influence the choice of PT such as bus, metro, and tram.

Meanwhile, a few publications that include AVs or SAVs into the discrete choice model have been found. For example, Winter et al. (2017) designed a stated preference (SP) experiment and developed multinomial logit model and nested logit model to study mode choice among car-sharing, private car, PT and SAV in the Netherlands. The relatively complex choice tasks include the cost of the trip, cost for parking, travel time walking time, and time for finding a parking spot. However, the results show that the waiting time of SAVs has no significant impact, comparing that of the bus. Meanwhile, Krueger et al. (2016) developed a mixed logit model based on SP data to examine the travel behaviour impacts of SAV. The results show that service attributes including travel time and travel cost are significant determinants of SAV use and acceptance. Moreover, Fagnant et al., (2015) and Krueger et al. (2016) estimated the value of time and willingness to pay of AVs and SAVs, showing an opposing view that waiting time is a critical service attribute of SAV operations.

2.2.2 Individual-Specific Variables

The results based on general mode choice literature review indicate that socio-economic variables (such as gender, age, number of children, trip purpose, number of cars in the household, marital status, income) have effects on the propensity to travel by conventional car or PT (Atasoy et al., 2006).

Concerning the influence of personal and household characteristics on the choice to travel by AVs or SAVs, the findings of previous research do not provide consistent conclusions. In terms of gender, according to Becker & Axhausen (2017), these studies found that men are more likely to adopt autonomous vehicles than women (Prateek Bansal, Kockelman, & Singh, 2016; Kyriakidis, Happee, & De Winter, 2015; Payre, Cestac, & Delhomme, 2014; Schoettle & Sivak, 2014; Zmud, Sener, & Wagner, 2016). The only study counteracting this trend is based on a focus group study which involves 32 participants (KPMG, 2013).

Assessing age as a factor, some claim that younger people have a higher interest in AVs and are more open to adopting them (Bansal et al., 2016; Megens, 2014; Schoettle & Sivak, 2014; Ipsos Mori, 2014). Other study stated that SAVs could constitute an attractive mobility option for the elderly or individuals too young to drive (Fagnant et al., 2015). Nonetheless, Krueger et al. (2016) found the empirical evidence which suggests that the cohort of elderly travellers is highly heterogeneous and motives of the use of different modes may vary across cohort subgroups.

Furthermore, none of the reviewed studies showed that income had a significant effect on intentions to use the new autonomous technology (Becker & Axhausen, 2017), but some positive relationship between willingness to pay for an autonomous feature and income of the respondents has been observed by Bansal et al. (2016) and Kyriakidis, Happee, & De Winter (2015).

In addition, some other factors such as education level and presence of children also have been studied, but only a few studies observed a significant effect. Some of the discrete choice models examined the individual characteristics of potential AV or SAV adopters. Haboucha et al. (2017) drew from SP data to investigate car owners' propensity to switch to SAVs. The study found that individuals with higher education level favour autonomous vehicles. Meanwhile, regarding the respondents having children, additional children in the household increase the likelihood of choosing SAVs. Interestingly, an opposing finding, by Zmud et al. (2016), is that households with children are less likely to indicate an intent to use AV than households without children.

Other than the socio-economic variables, some other factors relating to current travel behaviours also play a role. Krueger et al. (2016) noticed that individual's current modality style strongly influence the propensity to choose SAVs. For example, car users (drivers) are more likely to switch to use SAV than PT users. Nevertheless, Krueger et al. (2016) emphasised that the characteristics of potential SAV adopters are actually vague, since there is little to no theoretical or empirical evidence that can be considered to segment potential SAV users.

Regarding the adoption factors of flying vehicles, only few survey results were found concerning public opinions. Sivak & Schoettle (2017) performed a survey in the United States and concluded that about one-sixth of 508 respondents have very positive general opinions about flying cars, while males tend to have more positive opinions than females, and positive ratings increased with decreasing age. Another worldwide survey concerning pilotless planes, based on options of about 8000 respondents, was performed by UBS in 2017. Similar findings showed that younger and more educated respondents are more willing to fly on a pilotless plane.

2.2.3 Attitudinal Variables

In general, attitudinal factors such as the preference for convenience, comfort, flexibility and environmental concern have been found to influence transport mode choice concerning conventional transportation modes (Vredin Johansson, Heldt, & Johansson, 2006).

In terms of attitudinal variables' effects on opinions about autonomous vehicles, current existing literature have examined the following aspects. One aspect that has been highlighted is safety concerns. Haboucha et al. (2017) reviewed the literature and summarised the negative safety concerns triggered by the technical error, as well as positive finding that AVs can drastically reduce the number of crashes. Moreover, as one of the positive factors associated with AVs, the environmental friendliness has been recognised by Howard & Dai (2014). Haboucha et al. (2017) also proved that respondents express greater concern for the environment are more likely to use SAVs. Besides, Bansal et al. (2016); Schoettle & Sivak (2014); KPMG (2013) found the significant positive effects of technology awareness. Last but not least, Howard and Dai (2014) mentioned that those individuals more likely to use self-driving taxis are those who place high importance on amenities. And Winter et al. (2016) further discussed that vehicle automation has a strong impact on mode preference.

Concerning the psychological aspects which might affect the adoption of flying vehicles, safety problem has been recognised as one of the first psychological barriers that need to be overcome (Lineberger et al., 2018). The survey result of Sivak & Schoettle (2017) showed that the majority of respondents are “very concerned” about the overall safety of flying vehicles. And another critical finding is that fully autonomous flying vehicles are preferred over those operated by a professional with an appropriate pilot license, which indicates that the level of vehicle automation may also affect the adoption of the new mode.

2.3 Review of Choice Modelling

The following section gives a review of the fundamental theory of choice modelling, laying a theoretical foundation regarding the methodology applied for this thesis.

2.3.1 Overview of Choice Modelling

Discrete choice models describe decision makers’ choices among alternatives (Train, 2009, p.11). According to Ben-Akiva & Lerman (1985), discrete choice modelling is an econometric means of predicting the behaviour of users based on individual choice behaviour theory which is a collection of procedures that defines the following four elements: the decision maker, the alternatives, attributes of alternatives, the decision rule.

The utility is an indicator of value to an individual, and it is derived from the attributes of alternatives or sets of alternatives (Koppelman & Bhat, 2006). Discrete choice models are usually developed under an assumption of utility maximisation by the decision maker (Train, 2009, p.14). The utility maximisation rule is associated with a function containing attributes of alternatives and characteristics of individuals that describe an individual's utility valuation for each alternative. And the rule also states that an individual chooses the alternative with the highest utility (Koppelman & Bhat, 2006). Regarding the choice probability, which results from the difference in utility, not its absolute level is decomposed into the observed and unobserved parts, from the perspective of decision-maker. The utility of any given alternative i for any given individual q is a combination of a systematic element V_{iq}, and a random component, as shown in Equation 2.1.

$$U_{iq} = V_{iq} + \mathcal{E}_{iq} \tag{2.1}$$

where

U_{iq}: utility of the ith alternative for the qth individual,

V_{iq}: systematically derived element of the ith alternative for the qth individual,

$\mathcal{E}_{iq}$: error component V_{iq} can be.

(Louviere et al., 2000, p.38)

Suppose there is a set of alternatives A, the key assumption is that individual q will choose alternative i over alternative j if and only if the utility of option i is greater than that of option j, or $U_{iq} > U_{jq}$. And this equation can be expanded using Equation 2.1 yields:

$$V_{iq} + \mathcal{E}_{iq} > V_{jq} + \mathcal{E}_{jq} \tag{2.2}$$

or

$$V_{iq} - V_{jq} > \mathcal{E}_{jq} - \mathcal{E}_{iq} \tag{2.3}$$

(Louviere et al., 2000, p.40)

As the error component cannot be estimated by definition, $\mathcal{E}_{jq} - \mathcal{E}_{iq}$ cannot be calculated, the analyst has to calculate the probability that $\mathcal{E}_{jq} - \mathcal{E}_{iq}$ will be less than $V_{iq} - V_{jq}$ (Louviere et al., 2000, p.40). A random utility model (RUM) is generated to compute the probability that a given individual will select alternative i over j based on the assumption that $\mathcal{E}_{jq} - \mathcal{E}_{iq}$ varies in accordance with the predefined distribution (Twaddle, 2011).

Stated by Louviere et al. (2000, p.40), RUM is more complex yet based on a more realistic assumption about individual behaviour, offsetting the deficiency that all variables explaining preferences in the utility function cannot be entirely represented.

2.3.2 Utility-Based Choice Theory

As introduced above, the utility function consists of deterministic (or observable) part and error term, as shown in Equation 2.4. The following sessions explain the specific components of the utility function in detail.

$$U_{iq} = V(X_{iq}) + V(S_q) + V(X_{iq}, S_q) + ASC_{iq} + \mathcal{E}_{iq} \tag{2.4}$$

where

U_{iq}: utility of the i^{th} alternative for the q^{th} individual,

$V(X_{iq})$: systematically derived element of the i^{th} alternative for person q,

$V(S_q)$: the portion of utility related to characteristics of individual q,

$V(X_{iq}, S_q)$: the portion of utility resulted from interactions between the attributes of alternative i and the characteristics of individual q,

ASC_i: alternative-specific constant for alternative i,

$\mathcal{E}_{iq}$: error term.

The deterministic part of the utility of an alternative is a mathematical function containing the attributes of the alternative and the characteristics of the decision maker (Koppelman & Bhat, 2006). The function can be broken into components that are exclusively associated with the attributes of alternatives, exclusively associated with the characteristics of the decision maker, and represent interactions between attributes of alternatives and characteristics of the decision maker (Koppelman & Bhat, 2006).

Utility Associated with the Attributes of Alternatives

The attributes considered for inclusion are service attributes which are measurable and may influence the decision making (Koppelman & Bhat, 2006). Measures of these attributes vary over alternatives for the same individual and also among different individuals (Koppelman & Bhat, 2006). These attributes can be either quantitative or qualitative. In the transportation-related field, the quantitative attributes can be, for instance, travel cost, travel time, while the examples of qualitative attributes include comfort level of the transport modes, the reliability of the transport services, and so on. This portion of utility can be represented using Equation 2.5.

$$V_{iq} = \sum_{k=1}^{K} \beta_{iq} X_{ikq} \quad (2.5)$$

where

V_{iq}: systematically derived element of the ith alternative for individual q,

β_{iq}[4]: alternative-specific utility parameter,

X_{ikq}: independent attribute.

(Louviere et al., 2000, p.39)

In order to include the qualitative attributes into the model, all possible levels of the variable are required to be identified first. After setting one of the levels as a base level, a binary variable (0 or 1) could be introduced for all levels except the base case. According to Bierlaire et al. (n.d.), if a qualitative attribute has K levels, $K-1$ binary variables should be introduced in the model.

Utility Associated with the Characteristics of Decision-maker

Different from attributes of the alternatives, the characteristics of the decision maker only vary across individuals and do not differ across alternatives. The differences across individuals can be represented by socio-demographic variables. Similar to the attributes of alternatives, socio-demographic variables can also be described either quantitatively or qualitatively. The characteristics such as age and income can be considered as numerical and continuous quantitative variables, while attributes like sex and education level can represent the qualitative characteristics of the individuals. This portion of utility can be represented using Equation 2.6.

$$V(S_q) = \sum_{m=1}^{M} \beta_{imq} S_{mq} \quad (2.6)$$

[4] The parameter can be generic or alternative specific, depending on the situation. For example, deciding whether parameters of travel time is generic or alternative specific depends on the assumption that a minute has/has not the same marginal utility whether it is incurred on different transport modes.

where

β_{imq}: parameter which defines the effects in change of m^{th} characteristic of the individual q, concerning alternative i,

S_{mq}: value of the m^{th} characteristics for individual q.

To model heterogeneity based on the qualitative attributes, Bierlaire et al. (n.d.) introduced a *segmentation* strategy, namely, when the qualitative variable has N levels, N segments in the population are characterised. When individual q is associated with level n, the level represented by δ_{nq} is defined as value 1. Otherwise, δ_{nq} equals to 0. When introducing a parameter β_1^n for each level, β_{1q} of alternative i can be defined as Equation 2.7.

$$\beta_{1q} = \sum_{n=1}^{N} \beta_1^n \delta_{nq} \tag{2.7}$$

Moreover, according to Train (2009, p. 19), *only differences in utility matter*, the socio-demographic attributes can only enter the model if they are specified in ways that capture differences across alternatives.

Utility Defined by Interactions Between Alternative Attributes and Decision-maker Characteristics

Another component of deterministic part of utility takes into account differences in how attributes are evaluated by different decision makers (Koppelman & Bhat, 2006). Both quantitative and qualitative characteristics of decision makers may affect the evaluation of attributes. One way to evaluate the influence of a certain socio-demographic attribute is to examine how the preference of alternatives change by the change of this attribute, independent from the attributes of alternatives.

Error Term

Other than the deterministic component, an error term ($\mathcal{E}_{iq}$) is also included in the utility function. The inclusion of the error term accounts for the fact that the analyst is not able to completely and correctly measure or specify all attributes that affect individual's decision making (Koppelman & Bhat, 2006). According to the assumption of random utility theory concerning error term distribution, a wide range of distributions could be used to represent the distribution of error terms over individuals and alternatives. The formulation of various choice models based on different error distribution assumptions will be shown in Section 2.3.3.

Alternative-specific Constants

It is often reasonable to specify the observed part of the utility to be linear in parameters with a constant (Train, 2009, p.20). This constant is called the alternative-specific constant (ASC). For an alternative, ASC captures the average effect on the utility of all factors that are not included in the model (Train, 2009, p.20). When ASCs are involved, the unobserved portion of utility, $\mathcal{E}_{iq}$, has zero mean by construction. And if $\mathcal{E}_{iq}$ has a nonzero mean when the constants are not included, then adding the constants makes the remaining error have zero mean (Train, 2009, p.20). It is, therefore, reasonable to include ASCs for all alternatives. According to Bierlaire et al. (n.d.), ASCs can also vary across individuals.

Recall that *only differences in utility matter*, which means that only differences in ASCs matter, not their absolute levels (Train, 2009, p.20). Therefore, the researcher can only estimate the differences in ASCs. To achieve that, the researcher could normalise the specification by setting the ASC of one alternative to zero. So in general, with i alternatives, at most $i - 1$ ASCs can enter the model, with the remaining one normalised to zero (Train, 2009, p.20).

Specifying and estimating a discrete choice model is a complex process. There are two statements which summarise the essential aspects of the behavioural decision process. One is that *only differences in utility matter*, the other one is that *the overall scale of utility is irrelevant*, meaning that neither adding a constant to the utility of all alternatives nor multiplying each alternative's utility by a constant will change the decision maker's choice (Train, 2009, p.23).

2.3.3 Formulation of Particular Models

The mathematical form of a discrete choice model is determined by the assumptions made regarding the error components distributions. The most common assumption in the modelling literature is that errors are normally distributed (Koppelman & Bhat, 2006). This assumption leads to the formulation of probit models. However, because such type of models do not have a closed-form solution[5], and therefore can be difficult to solve in practice. An alternative

[5] An equation is said to be a *closed-form solution* if it may be solved using mathematical operations and does not require complex, analytical calculations such as integration each time a change occurs somewhere within the system (Hensher et al., 2015, p.518).

distribution assumption which is called Gumbel (or extreme-value) distribution leads to the formulation of logit models.

Multinomial Logit Model

Many axioms have been developed to make the individual choice model operationally tractable, among which, the mainly selected one is known as Independence-from-Irrelevant Alternatives (IIA). IIA states that the ratio of the probability of choosing one alternative over the probability of choosing the other is unaffected by the presence or absence of other alternatives (Louviere et al., 2000, p.44). The IIA property implies that the random elements ($\mathcal{E}_{iq}$) are independent across alternatives and are identically distributed (IID) (Louviere et al., 2000, p.45). One of the most extensively used distribution is the extreme value type one (EV1) distribution. The multinomial logit (MNL) model is formed based on the assumption of EV1 distribution, IIA and IID. And Equation 2.8 represents the MNL choice model consistent with the above assumptions.

$$P_{iq} = \frac{e^{\mathrm{Viq}}}{\sum_{j=1}^{J} e^{Vjq}} \qquad (2.8)$$

where

P_{iq}: probability of selecting alternative i,

V_{iq}: systematic component of the utility of alternative i,

V_{Jq}: systematic component of the utility of alternative j.

(Train, 2009, p.36)

The MNL structure has been widely used for transport mode choice models primarily due to its simple mathematical form and ease of computation. However, the ease of estimation comes at a price in its IIA property which is a major limitation of MNL model as it implies an equal competition between all pairs of alternatives (Koppelman & Bhat, 2006). In many cases, this restriction can lead to violations. For example, when introducing a new mode or making an improvement to an existing mode, the change will reduce the probability of current modes in proportion to their probabilities before the development (Koppelman & Bhat, 2006). Or in another case, when some part of the alternatives are likely to be more similar to each other than they are to either of the other alternatives, such similarities, if not included in the deterministic part of the utility function, will lead to correlation between the errors associated with these alternatives (Koppelman & Bhat, 2006). To overcome the limitation of MNL model, different models are expected to be derived from different assumptions concerning error term distributions.

Nested Logit Model

According to Train (2009, p.77), a nested logit (NL) model is appropriate when the set of alternatives faced by a decision maker can be partitioned into subsets, called nests. Alternatives in a common nest exhibit a higher degree of similarity and competitiveness than alternatives in different nests (Koppelman & Bhat, 2006). The NL model represents a partial relaxation of the IID and IIA assumption of the MNL model (Hensher et al., 2015, p.518). Specifically, IIA holds within each nest, while it does not hold in general for alternatives in different nests.

In order to make it more illuminating, the deterministic component of utility can be decomposed into two parts. One part is constant for all alternatives within a nest, and the other part varies over alternatives within a nest. The utility function can be written as Equation 2.9.

$$U_{iq} = W_{kq} + Y_{iq} + \mathcal{E}_{iq} \tag{2.9}$$

for $i \in B_k$, where

W_{kq} depends only on variables that describe nest k,

Y_{iq} depends on variables that describe alternative i.

(Train, 2009, p.82)

The choice probability of alternative $i \in B_k$ can be expressed as the product of two probabilities, namely, the probability that an alternative within nest B_k is chosen and the probability that the alternative i is chosen given that an alternative in B_k is chosen, as can be seen from Equation 2.10.

$$P_{iq} = P_{iq|B_K} P_{qB_K} \tag{2.10}$$

In particular, $P_{iq|B_K}$ and P_{qB_K} can be expressed as Equation 2.12 and Equation 2.11, respectively.

$$P_{qB_K} = \frac{e^{W_{kq}+\lambda_k I_{kq}}}{\sum_{l=1}^{K} e^{W_{lq}+\lambda_l I_{lq}}} \tag{2.11}$$

$$P_{iq|B_K} = \frac{e^{Y_{iq}/\lambda_k}}{\sum_{j \in B_K} e^{Y_{jq}/\lambda_k}} \tag{2.12}$$

where
$I_{kq} = \ln \sum_{j \in B_K} e^{Y_{jq}/\lambda_k}$

λ_k measures the degree of independence in unobserved utility among the alternatives in nest k

I_{kq} is the inclusive utility[6]

k represents nest k

I represents other nests

(Train, 2009, p.82)

Regarding computation effort, similar to MNL model, the NL model is relatively straightforward to estimate and offers the added benefit of being a closed-form solution (Hensher, Rose, & Greene, 2015, p.518).

Mixed Logit Model

The more advanced mixed logit (ML) model can explain individual differences in the mean of the attribute levels (Hensher et al., 2015, p.606). The taste heterogeneity can be modelled based on the decomposition of mean and standard deviation of one or more random parameters (Hensher et al., 2015, p.606). The utility function associated with alternative i, as evaluated by each individual q, is represented by the following Equation 2.13.

$$U_{iq} = \beta_q * Xiq + \mathcal{E}_{iq} \tag{2.13}$$

The component β_q is not observed by the analyst and is treated as a stochastic influence and is assumed to vary across individuals. β_q is determined by, where θ are the parameters of the distribution of β_q over the sample, such as the mean and standard deviation of β_q (Hensher et al., 2015, p.606; Train, 2009; Megens, 2014). For a given value of β_q , the conditional probability that individual q chooses alternative i is represented by Equation 2.14.

[6] The inclusive value or inclusive utility of nest B_k links the upper and lower models by bringing information from the lower model into the upper model. It is also called the *log-sum term.* (Train, 2009, p.83)

$$Liq(\beta q) = \frac{e^{\beta_q * X_{iq}}}{\sum_i e^{\beta_q * Xiq}} \quad (2.14)$$

As β_q is not given, the unconditional choice probability is the expected value of the logit probability over all the possible values of β_q , that is, integrated over these values, weighted by the density of β_q (Hensher et al., 2015, p.607). The Equation 2.15 shows the unconditional probability that individual q chooses alternative i.

$$P_{iq} = \int Liq(\beta) f(\beta|\theta) d\beta \quad (2.15)$$

where

$Li(\beta)$: likelihood of an individual's choice if they had this specific β,

$f(\beta|\theta)$: density of β where θ are the fixed parameters of the distribution,

P_{iq}: probability of individual q selects alternative i.

However, when applying ML modelling approach, estimating the parameters is time-consuming, and parameters are difficult to interpret (Megens, 2014).

2.3.4 Maximum Likelihood Estimation

Due to the fact that the sample is randomly drawn and is exogenous to the choice being analysed, Train (2009, p. 61) assumes that the explanatory variables entering representative utility are independent of the unobserved component of utility. As the logit probabilities have a closed form, the maximum likelihood estimation can be applied (Train, 2009, p. 61).

Assuming that each decision maker's choice is independent of that of other decision makers, the probability of each person q choosing the alternative i that based on the observation can be written as Equation 2.16.

$$L(\beta) = \prod_{q=1}^{Q} \prod_{i} \left(P_{iq}\right)^{y_{iq}} \quad (2.16)$$

where

y_{iq} equals 1 if person q chose alternative i and zero otherwise,

P_{iq}: probabilities of individual q chooses alternative i,

β: a vector containing the parameters of the model.

As it is easier to maximise the logarithm of the likelihood function, rather than the likelihood function itself (Louviere et al., 2000, p. 66), the log-likelihood function is in Equation 2.17.

$$\mathcal{L}(\beta) = \sum_{q=1}^{Q} \sum_{i} y_{iq} \ln P_{iq} \tag{2.17}$$

If the necessary computations are mathematically tractable, the maximum of the likelihood function can be found when its derivative with respect to each of the parameter is zero.

$$\frac{d\mathcal{L}(\beta)}{d\beta} = 0 \tag{2.18}$$

Recall the utility with linear parameters ($V_{iq} = \beta' X_{iq}$), using Equation 2.17 and the formula for the logit probabilities, Equation 2.18 becomes Equation 2.19.

$$\sum_{q} \sum_{i} \left(y_{iq} - P_{iq} \right) X_{iq} = 0 \tag{2.19}$$

However, regarding some models such as probit and mixed logit, since the resulting integral does not have a closed form, the maximum simulated likelihood methods have to be applied. (More details can be found in (Train, 2009))

2.3.5 Model Outputs

The following section will discuss the results which can be obtained as a consequence of the maximum likelihood estimation process. The results include estimated utility parameters and their statistical significance, measurement of goodness of fit for the model, and behavioural outputs of choice models.

Utility Parameters and Their Statistical Significance

An estimated of β_{ik} can be interpreted as an estimate of the weight of attribute k in the utility function V_i of alternative i (Louviere et al. 2000, p.51). The parameter can be generic or alternative-specific specified for an attribute that exists in more than one utility function across the choice set (Louviere et al. 2000, p.51). Given estimates of βs, an estimate of V_{iq} and U_{iq} can be calculated correspondingly. To test the statistical significance of the utility parameters, the maximum likelihood procedure allows the calculation of asymptotic standard errors for the $\hat{\beta}$s in the model and use these to test the statistical significance of individual βs using asymptotic t-tests (Louviere et al. 2000, p.51). Typically, the mean utility parameters which have sufficiently small standard errors are expected to be gained to well represent the influence of the particular attribute in explaining the level of utility associated with each alternative (Louviere et al. 2000, p.52). The t-value, namely the ratio of the mean parameter to its standard error, is desirably 1.96 or higher so that one can have 95% or greater confidence that the mean is statistically significantly different from zero (Louviere et al. 2000, p.52). However, several reasons could explain the insignificance of the parameters, for example, the involvement of outliers and missing data, and the fact that the attribute is simply not important, and so on.

Goodness-of-fit Tests

For measuring how well the discrete choice models fit the data, a statistic called the likelihood ratio index is often used (Train, 2009, p.68). This index is analogous to R^2 in regression analysis and is defined as in Equation 2.20.

$$\rho^2 = 1 - \frac{\mathcal{L}(\hat{\beta})}{\mathcal{L}\,(0)} \tag{2.20}$$

The comparison is made based on the log-likelihood function represented by $\mathcal{L}$, evaluated at both the estimated parameters and at zero for all parameters (Train, 2009, p.68). If everything else being equal in a specification testing, it is usually valid to say that the model with the higher rho-squared value (ρ^2) fits the data better.

One limitation of rho-squared measures is that the rho-squared values improve no matter what variable is added to the model independent of its importance. Meanwhile, there are no guidelines for evaluating a good rho squared value (Koppelman & Bhat, 2006). One approach to those problems is to improve on the rho squared value in Equation 2.21 by adjusting it for degrees of freedom (K).

$$\bar{\rho}^2 = 1 - \frac{\mathcal{L}(\hat{\beta}) - K}{\mathcal{L}\,(0)} \tag{2.21}$$

According to Bierlaire (n.d.), likelihood ratio test is to investigate parsimonious versions of a given specification, by introducing linear restrictions on the parameters. The null hypothesis of the test is that the restricted model is the true model, and if it is rejected, the unrestricted model is accepted. The test can be written as Equation 2.22.

$$-2\left(\mathcal{L}(\hat{\beta}_R) - \mathcal{L}(\hat{\beta}_U)\right) \sim X^2_{K,\alpha} \tag{2.22}$$

where

$\mathcal{L}(\hat{\beta}_R)$: log-likelihood of the restricted model,

$\mathcal{L}(\hat{\beta}_U)$: log-likelihood of the unrestricted model,

$X^2_{K,a}$: chi-squared distribution,

K: degrees of freedom,

α: significance level.

However, the likelihood ratio test can be applied only if one model can be obtained from the other one using linear restrictions of the parameters (Bierlaire, n.d.). For none of the two models is a restriction of the other, a so-called *Non-nested ratio test* is applied, and for that, adjusted rho square($\bar{\rho}^2$) is used to distinguish between the two competing models, the higher the value, the better the model represents the data (Bierlaire, n.d.). Moreover, according to Akaike (1974) and Schwarz (1978), AIC and BIC are suggested as good indicators when estimated model should be compared with another estimated model. The lower the value, the better the model represents the data (Kass & Raftery, 1995).

Some other testing methods such as Cox test, the Davidson and McKinnon J test can be used as well. If the reader is interested in more details about these methods, some works provided by Cox (1961), Cox (1962), Davidson & MacKinnon (1981), give a comprehensive explanation.

Behavioural Outputs

The random utility model represented by the MNL functions provides a powerful way to assess the effects of a wide range of policies (Louviere et al., 2000, p.57). The aggregate models (based on information from many individual interviews) can be used to estimate the elasticities of particular choices with respect to certain attributes, the marginal rates of substitution between attributes (e.g.willingness to pay (WTP)), and the likelihood of choosing a particular activity, given the levels of attributes offered as the significant choice discriminator (Louviere et al., 2000, p.58).

2.4 Review of Stated Choice Methods

SP surveys have been widely applied in the area of marketing and travel demand modelling (Yang, Choudhury, Ben-Akiva, Abreu Silva, & Carvalho, 2009). Especially when evaluating the introduction of a new product with private and public impacts, understanding and predicting the nature of individual and aggregate responses is essential to the estimation of the resulting costs and benefits (Louviere et al., 2000, p.1). In order to estimate choice models and understand the independent influence of various factors on the decisions made by individuals facing a specific choice situation, stated choice (SC) experiments need to be designed (Twaddle, 2011). An overview regarding the types of choice data and the methods for SC experimental design is provided in this section.

2.4.1 Comparing Stated Preference Data with Revealed Preference Data

When conducting a choice experiment, two types of preference data usually are collected. Revealed preference (RP) choice data is gained by observing individual's behaviour in the current market, depicting the world as it is now (Louviere et al., 2000, p.24). The other type of data that describes hypothetical decision contexts is termed SP data and can be collected from SC experiments. This can be a very useful quality in transportation-related studies because the effect of a new policy or measure can be estimated before it is implemented (Twaddle, 2011). Comparing with RP data, SP data is economical and usually can be collected much faster. Moreover, comparing with RP data, SP data is unlimited for developing reliable and valid models of behaviour change in response to variable change (Louviere et al., 2000, p.21). Furthermore, the most common limitation of RP data is that some explanatory variables are highly correlated in the marketplace. For instance, the longer the travel time is, the more expensive the fare is. This collinearity can be avoided by properly designing the SC experiment (Twaddle, 2011).

However, one of the limitations of SP data is its reliability. Under the hypothetical situation, there is a possibility that the respondents' expressed preferences are not consistent with their actual behaviour (Sanko, 2001). SP data seem to be reliable when respondents understand, are committed to and can respond to tasks (Louviere et al., 2000, p.24). To overcome the hypothetical bias, Morikawa (1989) introduced a powerful solution to combine RP and SP data, and the usefulness of such method is generally accepted. But to avoid drastic changes to the survey design and analysis, some other potential strategies to reduce the bias were suggested by Orme & Chrzan (2017), for example, adding *none* alternative to the choice tasks, and guiding people make choice decisions based on specific scenarios.

2.4.2 Selection of the Stimuli

Creating an SC design requires defining the alternatives that make up a choice set, determining the set of attributes that describe each alternative and, for each attribute, determining a set of attribute levels (values). Based on these elements, a set of specific choice contexts (including specific alternatives with specific levels of each attribute) to be presented to respondents can be defined (Walker, Wang, Thorhauge, & Ben-Akiva, 2017).

Selection of the Alternatives

When designing a choice experiment, one should begin with identifying alternatives. According to the utility maximisation rule, a universal but finite list containing every possible alternative must be initially defined (Hensher et al., 2015, p.104). If a complete list is too extensive to create a choice experiment with a considerable level of effort, the list of alternatives must be culled after in-depth alternative identification (Hensher et al., 2015, p.104). The first method to achieve this is to randomly select some alternatives from the universal but finite list of alternatives to assigning to each respondent. Another approach is to include only significant alternatives based on subjective decisions. Nonetheless, the second approach involves more practical consideration but violates the global utility maximisation assumption (Hensher et al., 2015, p.105).

In order to make a more realistic set of choice alternatives and thus ameliorate hypothetical bias from a modelling point of view, one of the alternatives in the choice sets is a *None of the above* option (Orme & Chrzan, 2017, p.195). Respondents may choose the *none* alternative for two reasons. First, respondents may find that no offering is sufficiently attractive (Johnson & Orme, 2002). Second, respondents may choose *none* as an option of avoiding difficult choices when they find all alternatives are equally attractive. In the second case, respondents treat the *none* choice just as another alternative (Haaijer, Kamakura, & Wedel, 2001).

Selection of the Attributes

After identifying the list of alternatives to be studied, the significant attributes need to be determined for those alternatives. The attributes included in the choice experiment can be common among the alternatives, such as travel time, or maybe alternative specific, such as the number of transfers on a trip using PT (Twaddle, 2011). Several principles are essential to be considered when refining attributes. Hensher et al. (2015, p.106) pointed out that the attributes should be unambiguous at first. The inclusion of any ambiguous variable is likely to increase the degree of unobservable variance in the decision-making process of the respondents and negatively affects the applicability of the results (Hensher et al., 2015, p.106). Moreover, the analyst must consider the cognitive inter-attribute correlations, which may affect the choice making. One related example could be the relationship between transport service quality and fare. If the decision makers assume that the higher the fare, the better the quality is, this may affect the analysis concerning the individual influence of the given attribute on the decision outcome (Twaddle, 2011). Thus, attributes should be independent, to avoid too much inferred influence on choice (Orme, 2002). Finally, controlling the cognitive complexity is also critical. As the degree of task complexity and difficulty arise with the increase of attributes, limiting the number of attributes helps to keep the experiment manageable and to maintain the data quality (ChoiceMetrics, 2018).

Selection of the Attribute Levels

Once the analyst has decided the attributes to be included, the corresponding attribute levels must be derived. The first decision is how many attribute levels to assign to each attribute, noting that the number of levels does not have to be the same for each attribute (Hensher et al., 2015, p.107). An example taken from Hensher et al. (2015, p.108) shows that if the analyst includes only two levels to describe an attribute, he or she would be forced to conclude that the utility relationship for the attribute is linear, while more complex utility relationship is detected as more levels are added. However, since task complexity increases as the complexity of levels increase, the analyst must find a balance between choosing enough attribute levels and restraining the complexity of the experimental design (ChoiceMetrics, 2018). Also, attribute levels can be either quantitative or qualitative, and they should cover the full range of possibilities (Orme, 2002). To determine the maximum and minimum attribute levels, one method is to combine focus group to sort out the attribute levels that represent the reality (Hensher et al., 2015, p.108). Another possibility is to review the extreme attribute levels from literature and previous experiments, and the modelling results will be used for assessing these values (Twaddle, 2011).

2.4.3 Experimental Design

Defined by Louviere et al. (2000, p.24), a designed experiment is a way of manipulating attributes and their levels to permit rigorous testing of certain hypotheses of interest. Several most commonly used experimental design methods are summarised as follows.

Full Factorial Design

The full factorial design consists of all possible combinations that elements can be combined to make choice sets (Walker et al., 2017). Each respondent is presented with all possible choice situations and is supposed to select one of the alternatives. The comprehensive combinations statistically allow the estimation of all the main and interaction effects of the attributes and attribute levels (Louviere et al., 2000, p.84).

$$S^{ff} = \prod_{j=1}^{J}\prod_{k=1}^{k} l_{jk} \tag{2.23}$$

Where

S^{ff}: total number of choice situations,

J: alternatives,

K: attributes of alternatives,

l: levels within the attributes.

(ChoiceMetrics, 2018)

However, typically the full factorial design is extremely large, making it impractical to implement in practice (Walker et al., 2017). One possibility to reduce the workload for each decision maker is to divide the choice situations among the respondents instead of assigning all situations to all respondents. Nevertheless, this method tends to lead to biased outcomes. Another common practice is to select the most important situations to present to each respondent for producing the desired statistical results (ChoiceMetrics, 2018). Some typical ways to reduce the full factorial to the fraction are explained in the following section.

Fractional Factorial/Orthogonal Design

The traditionally orthogonal design has been the predominant approach when building SP design (Walker et al., 2017). A design is orthogonal if all the attributes in the design are uncorrelated, and it is also desirable to evenly distribute (i.e., balance) levels among the choice tasks (ChoiceMetrics, 2018).

Typically, the so-called orthogonal coding is used for the labelling of the attribute levels, to reduce the complexity when creating the experimental design (Twaddle, 2011). To achieve the orthogonal coding, the sum of a column of attribute levels is expected to be zero. For instance, the attribute levels for an attribute with two levels could be assigned the values 1 and -1, while the attribute levels of an attribute with three levels could be labelled 1, 0 and -1 (Twaddle, 2011).

To limit the number of choice tasks that are shown to each respondent, a technique known as *blocking* is applied to orthogonally segment the design into smaller designs (Hensher et al., 2015, p.126). Although the block would not be orthogonal, the sum of the designs maintains orthogonality (Twaddle, 2011). Referring to the thesis work of Twaddle (2011), Louviere et al. (2000) suggested that the minimum number of choice tasks that must be included is six, to satisfy the properties of attribute level balance and degrees of freedom[7].

However, a typical shortcoming of orthogonal design is that orthogonality is lost when data is not collected for any of the choice situations (Twaddle, 2011). In another word, if blocks are used, and not all respondents complete the experiment, the design used at the point of estimation would not be orthogonal (Hensher et al., 2015, p.126). As Kuhfeld, Tobias, & Garratt, (1994) suggested, although orthogonal designs are widely used and are optimal for linear regression concerning producing unbiased estimated with minimum standard error, they are not necessarily efficient for discrete choice analysis.

Efficient Design

Efficient design is a new approach that has emerged in recent years. The target is to minimise the standard error of the parameters in the model specification, which can be achieved by

[7] Defined by Hensher et al. (2015, p.122), the degrees of freedom for an experiment are the number of observations in a sample minus the number of independent (linear) constraints, meaning the estimated β parameters.

utilising the asymptotic variance-covariance matrix (Walker et al., 2017). As the variance-covariance matrix is a function of the model parameters in discrete choice models, knowing the values of β parameters is the prerequisite (Walker et al., 2017). Nonetheless, the parameters cannot be known before the model estimation, and they are expected to be assumed towards the true values. And only under this condition, an efficient design will always outperform an orthogonal design (ChoiceMetrics, 2018). Otherwise, based on the findings of Walker et al. (2017), it might be risky to use an efficient design with uncertain priors.

Random Design

Another straightforward approach is a random selection of choice tasks from full factorial design (Walker et al., 2017). A finding from Walker et al. (2017) argues that the random design performs as well as any design, and it will perform even better if dominating alternative in the choice tasks is avoided. Although the conclusion is made based on a simplified model, the finding still draws many attentions from many researchers.

As one of the commonly used random design methods, a so-called *randomised design* strategy combines the characteristics of random design and orthogonal design in a way. Different from the purely random selection of choice tasks from full factorial design, this design follows the principle of attribute level balance and orthogonality, which means attribute level is uncorrelated with other attribute levels, although the orthogonality was given minor importance comparing to the strict orthogonal design. As many unique versions (blocks) of choice tasks are generated, 5 % to 10 % of efficiency is sacrificed compared to strict orthogonal design (Chrzan & Orme, 2000). However, many different combinations of elements will occur over a large sample of respondents, and thus the estimation of all effects can be robust. Meanwhile, each respondent receives a unique version reduces potential biases from learning and order effects (Sawtooth, 2017). Additionally, each option of a choice set is built by selecting attribute levels used least frequently in previous options for a specific respondent with the aim to minimise overlap, i.e., to keep the options in any task as different from one another as possible (Sawtooth, 2017).

In an SC experiment, alternatives can be unlabelled (generic) or labelled. In transport mode choice related study, the alternatives are labelled with different types of modes, and the names themselves convey information to decision makers (Louviere et al., 2000, p.120). This issue may have a very significant impact on model estimates and interpretation of results (Louviere et al., 2000, p.120). Moreover, regarding attributes and levels, when not all the alternatives share the same attributes or levels, the non-shared effects are defined to be alternative specific, according to Chrzan & Orme (2000). For example, walking might have different *travel time* levels than that of taking a bus, or, taking a bus might include *waiting time* attribute while walking do not. Here, *travel time* is a shared attribute with alternative-specific levels, while *waiting time* is an alternative-specific attribute. To handle alternative specific design efficiently, a fractional factorial approach *shifting* (Bunch, Louviere, & Anderson, 1996) is used for the shared attribute, and a strategy called L^{MN} (Louviere, 1988) is applied for the alternative-specific attribute.

Shifting method uses modular arithmetic to shift each combination of initial attribute levels by adding a constant that depends on the number of levels (Louviere et al., 2000, p.115). A *shifting* process of a simple experiment with three attributes each with two levels is given as an example below. The example is taken from (Sanko, 2001):

1. Produce one alternative from full factorial design. These four runs define the first alternative in each of four choice sets. All interactions between attributes are ignored.
2. Next to the three columns of the experimental design add three more columns; column 4 is just column 1 shifted so that column 1's 0 becomes a 1 in column 4, and 1 becomes (and wraps around to) 0[8]. The numbers in column 4 are just the numbers in column 1 shifted by one place to the right (and wrapped around in the case of 1). Likewise, column 5 and 6 are just shifts of columns 2 and 3.
3. The three columns 4 to 6 become the second alternative in each of the four choice sets. Note that the three columns just created are still uncorrelated with one another and that the value for each cell in each row differs from that of the counterpart column from which it was shifted (none of the levels overlaps).
4. Replace the level numbers with prose, and we have a shifted design.

Choice set	Alternative A			Alternative B		
	Att.1	Att.2	Att.3	Att.1	Att.2	Att.3
1	0	0	0	1	1	1
2	0	1	1	1	0	0
3	1	0	1	0	1	0
4	1	1	0	0	0	1

Table 2.1 Example of *Shifting* Design

[8] If using 3 levels attributes, 1 becomes 2, 2 becomes 3 and 3 becomes (wraps around to) 1.

When dealing with the alternative-specific attribute, one can use an L^{MN} design when one wants a design wherein choice sets each contains N alternatives of M attributes of L levels each (Chrzan & Orme, 2000). From this collective design, one selects the smallest, orthogonal main effects plan (Louviere et al., 2000, p.120). Another example is taken from Chrzan & Orme (2000), if there are three alternatives, and each is described by four three-level attributes, the collective factorial is 3^{3x4}, or 3^{12}. The smallest possible main effects plan is determined by the total degree of freedom required to estimate all implied main effects (Louviere et al., 2000, p.120). The more specific computing process is in accordance with Louviere et al. (2000) and is presented as follows. According to the theory, the total degrees of freedom is determined by summing the separate degrees of freedom in each main effect. Each main effect has precisely $L - 1$ degrees of freedom (equals to 2 in this example). There are exactly twelve main effects (3 x 4 attributes). Therefore, there is a total of 12 x 2, or 24 degrees of freedom. Referring to Addelman's design in 1962, the smallest requirement is 27 choice sets for this example (Chrzan & Orme, 2000).

3 Methodology

This chapter describes the two main methodologies of this research. In working towards the research objectives, an SP survey including SC experiment was used as a data collection instrument. Section 3.1 describes the design the SP survey and the implementation of data collection. The discrete choice modelling is used as the data analysis method in this research. A modelling framework to demonstrate the general process of model formulations and estimations is presented in Section 3.2.

3.1 Stated Preference Study

The initial data collection was carried out in Munich, which is the third largest city in Germany (Landeshauptstadt München, 2010). This section explains the structure of SP survey, the design of SC experiment, and the process of data collection in detail.

3.1.1 Questionnaire Design

Given that AT and AFT are not yet available and the study is about the future transportation mode choice, an SP survey was designed and performed.

The survey was structured in four parts. The first part includes questions about the respondents' current travel patterns, such as most frequently used transportation modes, car availability, satisfaction regarding the current travel pattern. The second part includes some attitudinal statements to measure perceptions that could influence acceptance of new transportation modes. Based on past studies and some priori hypotheses, the statements examined include attitudes towards the environment, towards new technology, towards autonomous transportation modes. The respondents were asked to indicate their level of agreement using a five-point Likert scale (ranging between *strongly disagree* to *strongly agree*). Next, a series of twelve SC tasks were provided in the third part to gain insights into the mode choice of the individual based on two scenarios concerning different trip purposes – commuting and non-commuting. Six choice tasks were presented for each scenario. In order to precisely understand the conditions that individuals prefer the flying mode, one independent question was given regarding the likelihood of choosing AFT based on the provided six trips purposes, including work (daily commute), education, business, shopping, performing leisure activities, and performing social activities. The survey ends with socio-demographic questions, such as age, gender, family situation, employment, education level, and income level, to gain insights into the characteristics of the respondents.

The demographic information has been considered as background attributes influencing the model formulation and analysis, while the attitudinal information has been used for interpreting the model results and explaining the findings, together with the coefficients estimated from the models.

3.1.2 Design of Stated Choice Experiment

A *focus group* workshop was organised for the preliminary settings of alternatives, attributes and attribute levels in November 2017. Some experts in the field of transport and aviation technology, as well as university students, have been invited to participate. The objectives were to find the aspects of the car, PT, and the new autonomous modes and services that could act as significant factors influencing mode choice, and to identify the critical attributes characterising the autonomous transportation modes that may be used in the SP survey. Nonetheless, the final decision regarding relevant alternatives, attributes and attribute levels was made based on the discussion results of the workshop, consulting the university professor, as well as the review of relevant studies.

3.1.2.1 Setting of the Scenarios

To reduce hypothetical bias to some extent, Chrzan & Orme (2000) suggested farming the choice questions to give respondents a realistic scenario in which to make their decisions. In order to determine the operational potential of AFT in Munich metropolitan region, a review of AFT service features and general travel pattern in Germany was conducted. Two categories of trip purposes were hypothesised that were anticipated to be feasible for AFT with a travel range of 15 km per direction[9].

1. Daily commuting trip: transportation modes are utilised during business days to transport individuals between a location near their place of residence to a location near their place of work, and vice-versa (adapted from (Vascik & Hansman, 2017)).
2. Non-commuting private trip: transportation modes are utilised to transport individuals between two locations on a non-commuting private trip with the intention of performing recreational or social activities (adapted from (Vascik & Hansman, 2017)).

Based on the literature review, the similar type of studies associated with AVs or SAVs include the respondent-specific reference alternative in the SP experiment part, however, due to the

[9] According to Follmer, Lenz, Jesske, & Quandt (2008), the range of 10km to 25 km per direction represents typical travel distances for work-related and business-related trips in Germany, and 15 km per direction has been selected to represent the value which is close to the average.

features of AFT and its service attributes uniqueness compared to the ground transportation modes, the hypothetical travelling distance of 15 km has been predefined. Other service attributes such as total travel time and total travel cost of different transport modes have been set based on the predefined travel distance.

3.1.2.2 Selection of the Alternatives, Attributes, and Levels

Alternatives

In order to fulfil the global utility maximising rule, a universal but finite list of all the existing alternatives must be compiled (Hensher et al., 2015). However, since the list of transportation modes in Munich metropolitan region contains many alternatives, it was necessary to cull the list of alternatives and select the most significant alternatives. Thus, it was decided to include four relatively comparable transportation mode alternatives in the SC experiment, the private car (driver), the PT alternative including the bus, tram, U-Bahn and S-Bahn, the AT, and the AFT. Meanwhile, an additional alternative *None of the above* was also included. Considering the predefined travel distance of 15 km, Follmer et al. (2008) shows that the majority of the trips within the distance of 10km to 25 km was made by private car and PT, while only less than 5 % of the trips within this travel range was made by walking or cycling. Therefore, the walking and cycling alternatives were omitted. However, as this omission violates the global maximising condition, some explanatory power of the model is lost (Twaddle, 2011). Meanwhile, this research aims to analyse the future transport demand, possibly around the time that AVs are in used. Therefore, it was decided to involve AT in the choice experiment as well.

Once the alternatives to be included in the choice experiment were decided upon, the attributes and attribute levels describing each of the alternatives should be determined. It was decided to include the following attributes and levels in the choice experiment to make the experimental design more manageable and efficient:

1. Three shared attributes with alternative-specific levels, including **total travel time, total travel cost, inconvenience indicated by total walking time and/or waiting time**. Each of the attributes was described by three levels based on alternatives. All the levels were set based on the one-direction trip scenario.
2. One alternative-specific attribute, which is **safety level**. The attribute was also described by three levels for alternative AT and AFT, while only one of the three levels was used to describe the corresponding crash rate of the current existing modes (private car and PT) in reality.

3. One constant attribute, which is **multitasking possibility**. The attribute was described by a constant level describing the property of the transportation modes, and it does not change across choice tasks.

In the next two subsections, the attributes and levels will be explained in a detailed manner. First, the attributes and levels representing the service characteristics of transport modes are described. Then the individual specific attributes and their corresponding levels, referred to as background attributes, are listed.

Mode Choice Attributes and Levels

Attribute 1: Total travel time

Based on the review of the current existing transportation mode choice studies, the vast majority of them included travel time as an attribute describing all the modes included in the experiment. In order to provide a general idea of total trip time, total travel time refers to door-to-door travel time per direction, which is composed of in-vehicle travel time, walking time, and/or waiting time.

In-vehicle travel time

The in-vehicle travel time was not included in the experiment as an independent attribute, but a component of total travel time. Referencing to the SP experiment designed for Munich (Twaddle 2011), the in-vehicle travel time attribute was integrated as a pivoted attribute. Regarding the car travel time, the reference attribute level of it was estimated using Google maps (Google Maps, 2017), while the pivoting values were adopted from Vrtic et al. (2009) who used a similar attribute in their mode choice analysis and produced a robust model from their results (Twaddle 2011). The pivoted attribute levels for car travel time were -40 %, 0 % (reference level) and +40 %. Since waiting time is not relevant for explaining the car (driver) option, while access time is quite short and can nearly be neglected, the pivoted attribute levels were considered as for **car total travel time**.

In terms of PT, the reference value of in-vehicle travel time was estimated using the trip planner provided by the MVV(MVV App, 2017), and the attribute levels of in-vehicle travel time for PT were pivoted around the reference value by -20 %, 0 % (reference level), +20 % (Vrtic et al. 2009). For AT, the levels were created for this experiment, based on the travel time of taxi services in Munich (Mytaxi App, 2017). Whereas concerning AFT, as no reference values can be found, the three levels of in-vehicle travel time are defined based on the travel distance (15 km) and the operation speed range of AFT (100km/h – 150km/h), considering one to two minutes take-off and landing time (Holden & Goel, 2016).

Attribute 2: Inconvenience indicated by total walking time and/or waiting time

As other components of total travel time, waiting time and walking time in a way indicate the inconvenience level when using a shared transportation mode. Although stated previously, the walking time and waiting time are not very important factors for travelling by **car**, three levels were included to balance the design. These levels were 0 minutes, 2 minutes, and 4 minutes.

In contrast, the walking time for PT was considered because it has been found to have a strong and significant influence on mode choice and PT use (Vrtic et al., 2009; Daniels & Mulley, 2013). The PT total walking time levels were decided to be pivoted around a reference value by -50 %, 0 % (reference level), +50 %, according to the survey result of Sarker (2015), concerning the walking distance to local PT in Munich area. The reference level of PT walking time was estimated based on the average walking distance, which is 0.72 km per direction in Munich (Moovit Public Transit Index, n.d.), and 5km/h average walking speed. Regarding PT waiting time, the headway (or frequency) of PT service in Munich[10] was considered. The 5-minute average waiting time was added to the walking time, and the summed values were used to indicate the **inconvenience level of PT**.

Regarding AT, waiting time can be assumed to be an important service attribute, from a user perspective. Meanwhile, waiting time is critical for the determination of vehicle fleet sizes and ultimately affects the operating cost of the service (Krueger et al., 2016). The attribute levels of AT waiting time were defined as 5 minutes, 10 minutes, and 15 minutes, referencing to the scenario set by Fagnant & Kockelman (2016) for the simulation of SAVs, as well as the waiting time of taxi services of Munich. Taking into account the point-to-point services provided by ODM services, walking time of AT was integrated into the waiting time, assuming that travellers have the knowledge of the estimated arrival time the AT they called. Therefore, the levels of waiting time were used to indicate the **inconvenience level of AT**.

[10] The buses, trams and U-Bahn in Munich has a 5- or 10-minute headway during daytime hours, and a 20-minute or 1-hour headway during the late evening and early morning (Twaddle 2011). The S-Bahn has a basic 20-minute headway, while there is a 10-minute headway produced by added train during peak hours in some branches.

For AFT, the attribute level of waiting time was defined considering the operation concept of Uber. Meanwhile, it was also taken into account the scenario that an extensive and distributed network of vertiports will be available for vehicle take-off, landing, and charging (Holden & Goel, 2016). Moreover, from the experimental design point of view, all levels of waiting time was examined and was kept less than all levels of total travel time for AFT, to make all choice tasks meaningful. Similar to the concept of AT, the walking time was integrated into the total waiting time, which indicates the **inconvenience level of AFT**.

To provide a general idea of the **total travel time**, the in-vehicle time, walking time, and/or waiting time were summed for **PT, AT and AFT** and displayed in one row in the choice tasks that were given to the respondents.

Attribute 3: Total travel cost

Similar to travel time, travel cost is another common attribute that was included by many mode choice studies and found to be a significant influential factor on mode choice. With regard to car travel cost, in order to represent the entire cost on a driver for using a car, it was decided to use an all-inclusive travel cost as car total travel cost, which include the depreciation per kilometre, the fuel cost, fixed costs associated with car ownership including insurance and tax, and variable costs including maintenance and repair (Twaddle, 2011). The **car total travel cost** attribute was included with pivoted attribute levels. The reference level 0.5 €/km was adopted from the median value given in the report provided by ADAC (2017), referring to the work of Twaddle (2011). Adopted from Vrtic et al. (2009), the attribute levels were pivoted by -30 %, 0 % (reference level), +30 %.

The fare of PT has been found to be the most influential factor on mode choice (Twaddle, 2011). The attribute levels for **PT total travel cost** (PT fare) were taken as the cost of an MVV single trip ticket for one or two zones, which is 2.90 € or 5.80 € considering the predefined travel distance. The lowest level (cheapest) was set to 1 € according to the price of the monthly discount ticket[11].

When it comes to the price levels of **AT total travel cost**, three attribute levels (9 €, 11 €, 13 €) were established, referencing to the SAV cost level set by Krueger et al. (2016) and Fagnant

[11]. The monthly discount ticket (IsarCardAbo) costs 55.20 € per month for travelling within one to two zones. The average cost per day per direction was approximately 1 €.

& Kockelman (2016). This parameterisation is consistent with the presumption that ATs will constitute a relatively low-cost mobility option, which can compete with the private car (Krueger et al., 2016). Meanwhile, taking into account the AFT alternative, the setting of AT attribute levels was intended to avoid that AFT would become an asymmetric dominate alternative.

For the AFT, the attribute levels were adopted from the VTOL trip prices estimated by Holden & Goel (2016). The estimated pricing was based on initial, near-term, and long-term scenarios, comparing with the price level of UberX and UberBlack. The three levels of **AFT total travel cost** included in the experiment were 15 €, 25 €, and 75 €, in reverse chronological order.

Attribute 4: Safety level

Safety or risk is not always included in the choice models because it is difficult to quantify and the potential passengers make it up. Therefore, the crash/fatality rate per 100 million passenger miles[12] was employed to specify the safety level in this experiment, to measure the impact of perceived safety on mode preference and the adoption of the autonomous modes. Making the levels more readable, the constant **safety level of the car** was named as *driving-level safety* and was defined as the reference level, while all levels of the other modes were represented as relative values. Thus, the **safety level of PT** was defined as *at least two times safer than driving-level-safety*, according to the work of Savage (2013) who found that the fatality risk of car drivers was about 17 times greater relative to transit modes in the US.

In order to investigate the perceived safety of AT and AFT, the lowest and highest levels were set based on the worst and best safety scenarios respectively. For **AT**, currently, the crash rate per million miles is more than double the rate involving conventional cars, according to the comparison result between crash reports of self-driving vehicle and the safety records for all conventional vehicles in the US in 2013. However, the ATs need to be twice as safe as human drivers, as many public and policymakers expected.

Moreover, the future safety level of flying cars is unknowable at the moment, as no regulation or air traffic management system is there yet to guarantee safe and efficient operations of flying cars. According to Holden & Goel (2016), Uber uses charted helicopters as a baseline for estimations, which is two times worse than driving-level safety. However, the company's sets

[12] About 160 million passenger km.

the goal to improve the safety level of eVTOLs two times safer than driving, regarding the number of fatalities per passenger mile. The safety levels of **AFT** were thus defined corresponding to the baseline and target scenarios.

Attribute 5: Multitasking possibility

As vehicle automation distinguishes the conventional transport modes and future transport modes considered in the experiment, multitasking possibility was selected from the potential user point of view. It was set as a constant attribute, which does not change across choice tasks but describes the mode property. And the utilities regarding this attribute is in fact captured by the ASCs. The levels of multitasking possibility for the car, PT, AT and AFT were defined as *No*, *In-part*, *Yes* and *Yes*, respectively, reflecting the levels of vehicle automation to some extent.

Summary of the Alternatives, Attributes and Attribute Levels

Table. 3.1 summarises the attributes and attribute levels that were described above. Moreover, as the influence of the individuals' demographic background and the attitudinal information is also considered in this study, a summary table including individual background attributes and levels are attached in Appendix A.

Alternative	Attribute	Attribute levels	Source
Car	Total travel time	18 Minutes, 30 Minutes, 42 Minutes (-40%, 0%, +40%)	Vrtic et al. (2009) Google map
	Total travel cost	5.25 €, 7.50 €, 9.75 € (-30%, 0%, +30%)	Vrtic et al. (2009) Twaddle (2011); ADAC report
	Inconvenience indicated by total walking time	0 Minutes, 2 Minutes, 4 Minutes	Created for this experiment
	Safety level	Driving-level safety	Created for this experiment
	Multitasking possibility	No	Created for this experiment
PT	Total travel time	38 Minutes, 49 Minutes, 61 Minutes	Vrtic et al. (2009) Twaddle (2011); Google map
	Total travel cost	1.00 €, 2.90 €, 5.80 €	MVV
	Inconvenience indicated by total walking and waiting time	15 Minutes, 17 Minutes, 19 Minutes	Sarker (2015); Moovit PT index
	Safety level	At least two times safer than driving	Savage (2013)
	Multitasking possibility	In-part	Created for this experiment
AT	Total travel time	28 Minutes, 40 Minutes, 52 Minutes	Created for this experiment
	Total travel cost	9 €, 11 €, 13 €	Krueger et al. (2016); Fagnant & Kockelman, (2016)
	Inconvenience indicated by total waiting time	5 Minutes, 10 Minutes, 15 Minutes	Fagnant & Kockelman, (2016); Munich taxi services
	Safety level	At least two times safer than driving Driving-level safety Two times riskier than driving	Patel (2017) LeBeau (2015)
	Multitasking possibility	Yes	Created for this experiment
AFT	Total travel time	12 Minutes, 17 Minutes, 21 Minutes	Created for this experiment
	Total travel cost	15 €, 25 €, 75 €	Holden & Goel (2016)
	Inconvenience indicated by total walking and waiting time	5 Minutes, 7.5 Minutes, 10 Minutes	Created for this experiment
	Safety level	At least two times safer than driving Driving-level safety Two times riskier than driving	Holden & Goel (2016)
	Multitasking possibility	Yes	Created for this experiment
None of the above	NA	NA	NA

Table 3.1 Summary of the Alternatives, Attributes and Attribute Levels in the SP Experiments

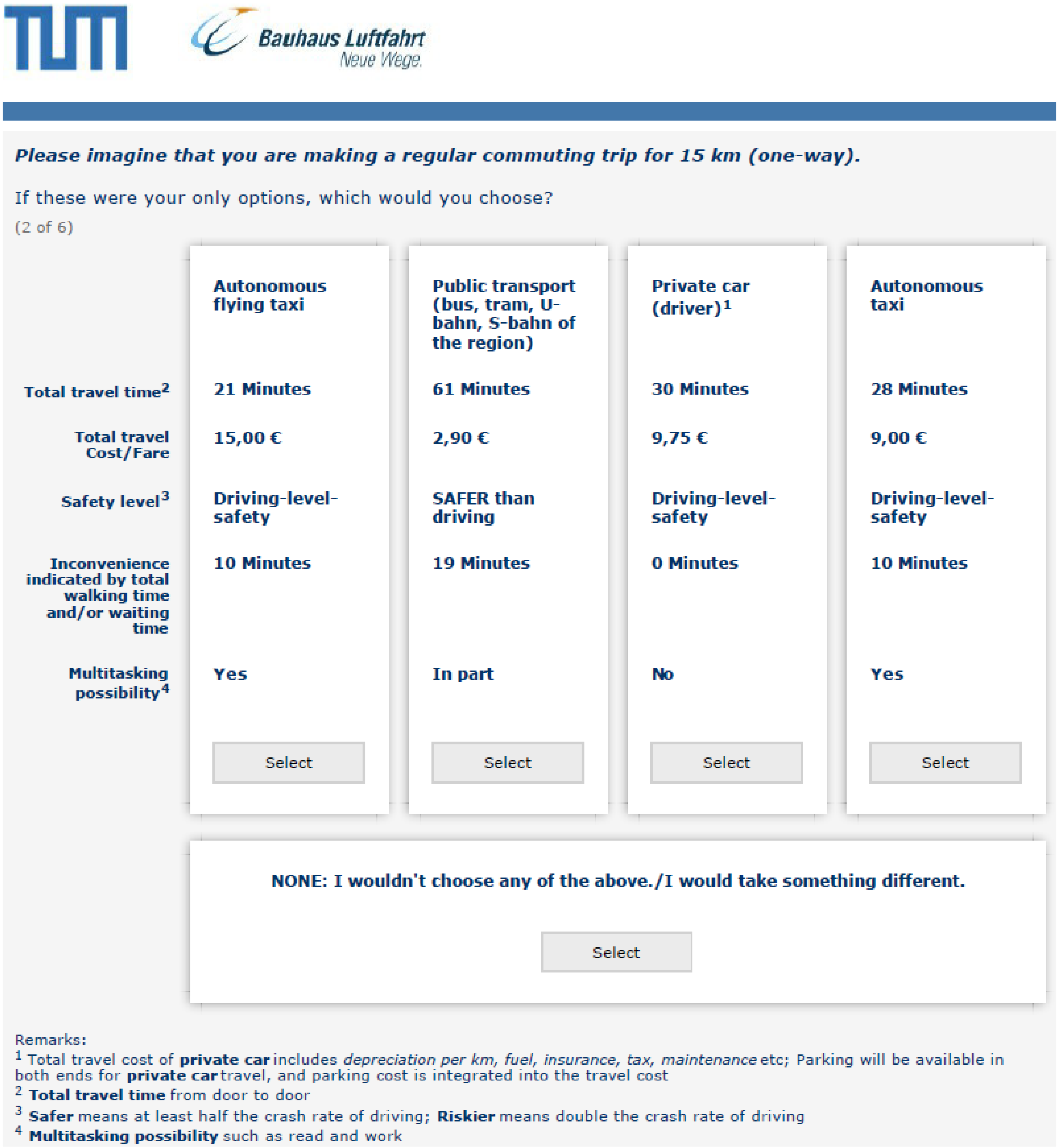
3.1.2.3 Setting of the Choice Sets

By applying the minimal overlap principle, six choice sets were created for each hypothetical scenario (twelve choice sets in total for both scenarios) using *random design*, the contents and orders of the choice sets are identical across different scenarios. Table. 3.2 provides an overview regarding the SC experiment setup.

Survey	**Design type**	**Number of versions**	**Number of hypothetical scenarios**	**Number of alternatives**	**Number of attributes**	**Number of choice sets**
Pilot	*Random design* (nearly orthogonal)	20 (English)	1 (Commuting)	5 (including *None of the above*)	5	9
Main	*Random design* (nearly orthogonal)	200 (German) 100 (English)	2 (Commuting and Non-commuting)	5 (including *None of the above*)	5	6 (for each scenario)

Table 3.2 Overview of the SC Experiment Setup

Based on *random design* strategy, each respondent receives a unique version of the design of choice experiment. An example of one of the choice tasks is shown in Figure. 3.1.



Please imagine that you are making a regular commuting trip for 15 km (one-way).

If these were your only options, which would you choose?

(2 of 6)

	Autonomous flying taxi	Public transport (bus, tram, U-bahn, S-bahn of the region)	Private car (driver)[1]	Autonomous taxi
Total travel time[2]	21 Minutes	61 Minutes	30 Minutes	28 Minutes
Total travel Cost/Fare	15,00 €	2,90 €	9,75 €	9,00 €
Safety level[3]	Driving-level-safety	SAFER than driving	Driving-level-safety	Driving-level-safety
Inconvenience indicated by total walking time and/or waiting time	10 Minutes	19 Minutes	0 Minutes	10 Minutes
Multitasking possibility[4]	Yes	In part	No	Yes
	Select	Select	Select	Select

NONE: I wouldn't choose any of the above./I would take something different.

Select

Remarks:
[1] Total travel cost of **private car** includes *depreciation per km, fuel, insurance, tax, maintenance* etc; Parking will be available in both ends for **private car** travel, and parking cost is integrated into the travel cost
[2] **Total travel time** from door to door
[3] **Safer** means at least half the crash rate of driving; **Riskier** means double the crash rate of driving
[4] **Multitasking possibility** such as read and work

Figure 3.1 Example of Questionnaire Webpage

3.1.3 Data Collection

In order to test the survey structure and to test the validity of the experimental design, a pilot test was implemented in a Munich-based interdisciplinary research institute with 28 participants, in January 2018. After the test, the survey has been improved based on the feedback and comments concerning the survey design, settings of attribute levels, as well as the expression of questions. One of the major changes was made regarding the settings of hypothetical trip purposes. Initially, nine choice tasks under the hypothetical scenario of *commuting trip* were provided. However, considering the presumption that autonomous flying taxi might be more attractive for other trip purposes, another hypothetical scenario of *non-commuting private trip* was added. Meanwhile, six choice tasks were used for each scenario instead of nine choice tasks, to maintain the respondents' workload to a manageable level.

Without an in-depth analysis of the estimation result of pilot mode choice model based on 252 (28 individuals x 9 observations/individual) observations, the valid model estimation has proved the validity of the survey design and the general feasibility of the choice modelling methodology applied.

The main survey was conducted during mid-February and April, 2018. In total 382 respondents entered the survey, but only 248 answers were completed and valid. The unsuccessful respondents, who did not complete the survey or were not the frequent travellers of Munich metropolitan region[13], were thus discarded from the results, in order to fulfil the research scope. Meanwhile, due to the extensive legal implications, the individuals aged younger than the unrestricted legal age of driving (18 years old in Germany) were not investigated in this study.

The survey was initially attempted to be implemented by in-person interviews. An attempt has been made to conduct the survey during work days. However, since the interviewing time was relatively long (about 20 minutes), while most of the working people tend to have a higher value of time (VOT) in Munich and were not willing to be involved, the *in-person interview* procedure did not allow to get a well-represented sample. Therefore, the decision was taken to gather data using a *respondent recruitment procedure*, i.e. distributing flyers at business campuses, universities, schools, residential areas, public transport stations with P+R services, parking lots, in order to capture the actively commuting population. Other than those locations, some digital flyers, along with invitation emails, have been distributed via emails, Linkedin, Xing and Facebook. The participants received the flyers along with the general explanation of the study scope and idea of the survey, as well as the instructions concerning the choice tasks. These were then followed by online interviews, which means that participants accessed the survey via the survey links stated on the flyer. This *respondent recruitment strategy* referred to the work of Kouwenhoven et al. (2014) who found that comparing with recruiting respondents from an internet panel, the *en-route recruitment* reduces the bias with respect to the VOT, as the

[13] Munich metropolitan region consists of the agglomeration areas of Munich (rural district included), Augsburg ((rural district included), Ingolstadt, Landshut (rural district included), Rosenheim (rural district included), Landsberg am Lech (“Munich Metropolitan Region,” n.d.).

respondents that participate in an online panel (which takes time, for a rather low monetary reward) might be expected to have a lower VOT than non-participants.

Survey	Number of versions	Total number of respondents	Number of successful respondents	Type of survey distribution
Pilot	20 (English)	28	28	Workshop
Main	200 (German) 100 (English)	289 (German) 93 (English)	195 (German) 53 (English)	Flyer distributions to recruit respondents

Table 3.3 Summary of the Survey Setup and Data Collection Result

3.2 Modelling Framework

This section gives a general description concerning the modelling framework. The exploratory analysis methods that have been attempted to be used are firstly described. As not all the attempts made was successful, only information that considered as useful input for the later-stage analysis is presented. Moreover, regarding the results of actual implementation of model formulations and estimations presented in chapter 5, a general framework of model development is presented in this section.

3.2.1 Exploratory Analysis

The exploratory analysis started from visualising data using parallel coordinates, to observe the relations between many variables. However, the plotted variables were factors with only a few levels, most of the observations fell one on top of another in a small number of trajectories, which indicates that parallel coordinates may not be well suited for visualising category data but multivariate and numerical data.

To further explore the demographical characteristics, market segmentation was performed based on several techniques. Firstly, the latent class segmentation based on the choice data was implemented. The analysis simultaneously estimates utility for each segment and the probability that each respondent belongs to each segment (Sawtooth, 2018). As a result, three segments were obtained, having the characteristic that the respondents within each group are relatively similar but the preferences are different from group to group. Nonetheless, as the demographic variables were not included in forming segments, the identified segments were not able to be explained by those background variables, and therefore, this method was not compatible with the scope of the exploratory analysis for this research.

Furthermore, factor analysis with *varimax rotation* was then performed to understand which characteristics are strong in determining potential groups (Atasoy et al., 2006), and to be able to see the relation between mode choice behaviour of individuals and their demographic characteristics, such as the socio-economic status, family status, current travel pattern. However, no distinct group characteristics could be observed according to the factor loadings. Nevertheless, when only the socio-economic status was involved, some relations between age, income and employment status were observed. For example, the youngest group (age between 18 and 25) tend to have lower income, and older group (age between 55 and 65) tend to be employed people, as can be seen from Table 3.4. Nevertheless, no clear segmentation was found through factor analysis. The results only gave a sign to the characteristics of potential groups that were considered in the later analysis, combined with the analysis results regarding SC experiment and the demographic characteristics presented in Section 4.2.

Variables	Factor1	Factor2	Factor3
Age			
18-25	0.549		
56-65		0.314	
Income			
< 500€	0.319		
500€ - 1000€	0.500		
2000€ - 3000€			-0.968
Employment Status			
Working people	-0.913	-0.379	
Student	0.948		
Others		0.991	
Education Level			
Bachelor	0.322		
	Factor1	Factor2	Factor3
SS loadings	2.896	1.495	1.257
Proportion Var	0.132	0.068	0.057
Cumulative Var	0.132	0.200	0.257
The degrees of freedom for the model is 168 and the fit was 44.6902			

Table 3.4 Factor Analysis Regarding Demographic Characteristics

3.2.2 Model Formulation and Estimation

To specify the utility functions, the procedure of starting from one parameter and adding the rest of them was followed. The quantitative attributes related to travel time and travel cost were included as linear parameters, while all the qualitative attributes including safety and all the socio-demographic variables were coded according to their categorical levels. After adding the ASCs, all other coefficients related to transportation service attributes, as well as the socio-demographic attributes, were first estimated as generic parameters. Only parameters yielding significant results and statistically improving the model fit were then included and estimated as alternative-specific parameters. Meanwhile, hypothesis testing was conducted regarding the alternative-specific parameters obtained. The tested parameters were carefully grouped If no significant differences were found.

Following the above specification procedure, not in all cases significant and robust coefficient could be estimated, the only statistically significant parameters were included in the final model structure (Winter et al., 2017).

The model estimations have been implemented in Python Biogeme (Bierlaire, 2016), using the optimisation algorithms BIO and CFSQP (Lawrence, Zhou, & Tits, 1994). First, two MNL models including alternative-specific and individual-specific variables were estimated, one with the choice of *none* excluded, while the other one including the choice of *none*. The models were obtained for the probabilities of choosing each alternative i as in the following equation.

$$P_{iq} = \frac{e^{\mathrm{Viq}}}{\sum_{j=1}^{J} e^{Vjq}} \qquad Repeated\ equation\ (2.8)$$

By checking the model results, the model with a better model fit was selected as a base for the further model development. In order to overcome the restrictive IIA assumption of MNL, the NL models specified with different nested structures were attempted to be estimated. Meanwhile, according to the estimation results of MNL, two specific groups of respondents were found to have particular potential interest regarding the alternative AT and AFT, it was thus decided to develop MNL based on profiles in order to further describe these groups of potential users. Following the similar procedure as estimating the general MNL models, the profile-based models including and excluding the choice of *none* were estimated in parallel. Furthermore, to reveal sources of systematic taste heterogeneity and deal with SP data consisting of multiple choice situations (twelve choice situations in this case), an ML model with panel effect was attempted to be developed for capturing the correlation between the error terms of the same individual. However, due to the limitations of time and computation efforts, this approach was only attempted to be applied for one of the user groups mentioned above. Since the integral does not have a closed form, the choice probability cannot be exactly calculated. Therefore, to approximately estimated the parameters of the ML model, simulation is applied. In this thesis, the parameters are specified to be normally distributed, and for any random value within the normal distribution, the parameter can be calculated by inversing the normal cumulative distribution for the specified mean and standard deviation (Megens, 2014). The logit probability L_{iq} is calculated with this parameter, and the choice probability P_{iq} is calculated by repeating this step and averaging the results according to Equation 3.1 (Train, 2009).

$$SP_{iq} = \frac{1}{R} \sum L_{iq}(\beta) \qquad (3.1)$$

where

SP_{iq} : simulated probability that individual q chooses alternative i,

R: number of draws of β.

The process of formulating and estimating the models mentioned above is summarised in Figure 3.2, as can be seen below.

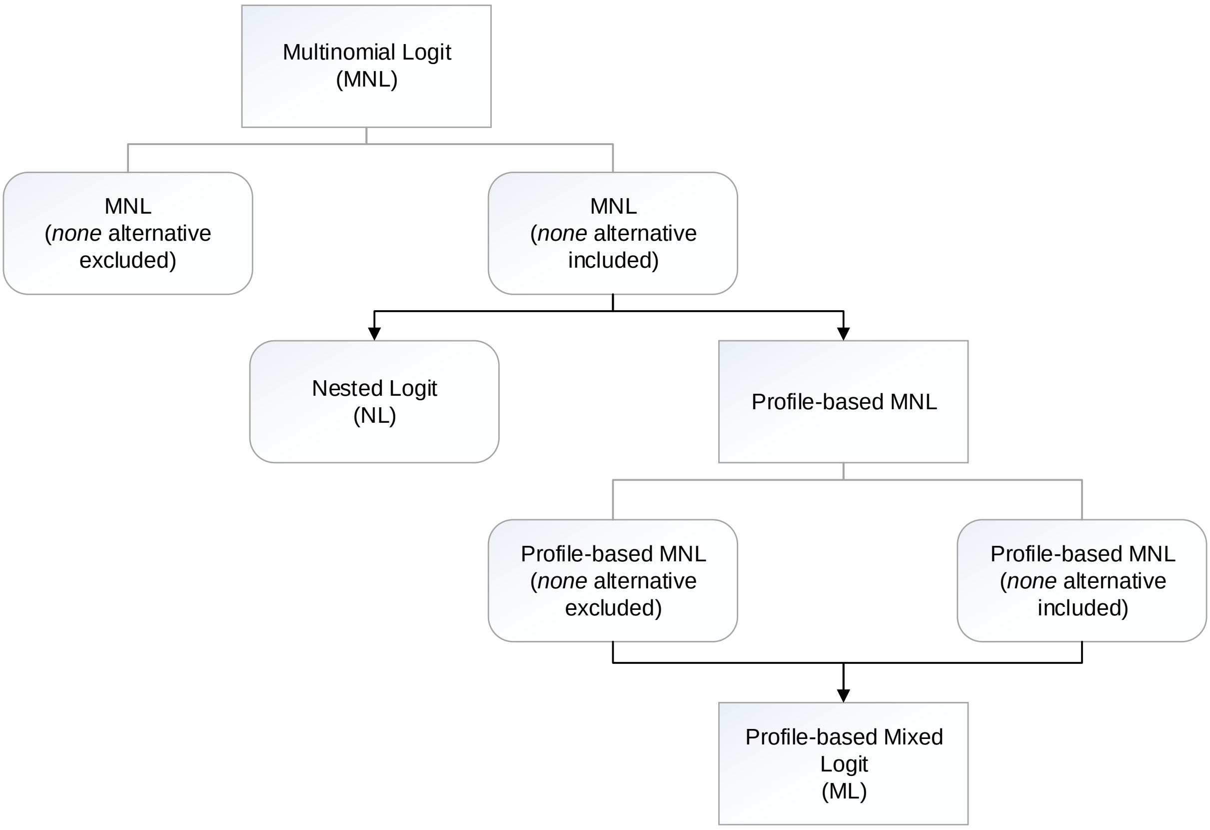


Figure 3.2 Model Development Process

4 Data Analysis

This chapter illustrates the result of preliminary data analysis, providing input for further inferential statistical analysis. Section 4.1 firstly presents the results of sample recruitment and processing of missing data. For thoroughly understanding the respondents' choice behaviour, the results of an in-depth descriptive analysis regarding the survey is provided in Section 4.2.

4.1 Description of the Research Sample

This section introduces the survey sample composition. In order to illustrate the socio-demographic characteristics in which the sample reflects correctly the population and the aspects where it could be improved, a comparison was made between the research sample and Census data (Statistische Ämter des Bundes und der Länder 2014, n.d.), as well as some statistics about average household income, car availability, and modal split. A summary of the sample characteristics is illustrated in Table 4.1 at the end of this subsection.

Although the *en-route recruitment* was employed, the survey was still online-based. Therefore, some statistics are not entirely representative of the entire population, as expected for an internet-based survey (Efthymiou, Antoniou, & Waddell, 2013). In general, gender, age, employment status and car availability situation were rather well represented, while education level, the presence of children and current transport mode share were less representative.

During the *en-route recruiting* process, it has been noticed that younger people seemed more interested in this research topic and more passionate to accept the survey flyers than older people, considering the fact that people more than 65 years old have less access to the internet (Dillman, Smyth, & Christian, 2014). Nevertheless, after the completion of the online distribution, the number of respondents aged between 46 to 65 years old has increased rather significantly. However, by investigating the profile of these respondents, it was noticed that the majority of the respondents have relatively higher education level, meaning at least Bachelor's degree. This could be explained by the fact that these segment of the population may be more likely to respond to online questionnaires (Efthymiou et al., 2013). Thus, it should be acknowledged that the different socio-economic factors could in a way lead to biased survey results.

Moreover, Dillman et al. (2014) also suggested that non-response should also be considered to achieve a better result from a survey. For that, some missing values were handled. According to Tabachnick & Fidell (2006), it is permissible to "fill in" the missing values using variable means or medians if there are only a few missing values (5 % of a sample). Therefore, all missing values which were less than 5 % and income were handled as follows based on such principle:

- *Gender*. Five respondents preferred not to specify the gender. These observations were assigned to the *Female* category.
- *Education*. Three respondents preferred not to specify the education level. These observations were assigned to the *Master's degree* level.
- *Employment*. Two respondents preferred not to specify the employment status. These observations were assigned to the *Employed* category.
- *Presence of Children*. Six respondents preferred not to specify the presence of children in the household. These observations were assigned to *Household without children* category.
- *Income*. Since almost 18 % of respondents preferred not to specify their income levels, the missing values of income were coded as *not available* (NA) as another category.

N = 248		Survey	2011 Census (ages 18-74)
Gender	Male	48.8%	48.6%
	Female	51.2%	51.4%
Age	18 - 25	18.1%	9.2%
	26 - 35	32.3%	21.7%
	36 - 45	20.2%	22.4%
	46 - 55	17.3%	22.2%
	56 - 65	10.9%	16.8%
	> 65	1.2%	7.7%
Employment	Employed – full time	61.3%	87.1%
	Employed – part time	9.3%	
	Student (university or college)	20.2%	2.9%[14]
	Unemployed	1.2%	2.2%
	Housemakers	0.8%	4.6%
	Others	6.5%	3.2%
Education	High school	8.9%	34.1%
	Apprenticeship with graduation	3.6%	40.7%
	Bachelor's degree	18.5%	22.7%[15]
	Master's degree/Diplom	60.1%	
	Ph.D	8.9%	2.5%
Presence of children	Households with children (0-17 years old)	21.4%	41.4%[16]
	Households without children (0-17 years old)	78.6%	58.6%[17]
			Average monthly disposable income in Munich (2016)
Income	< 500 €	3.2%	5060 USD (4220 Euro) per household[18]
	500 € - 1000 €	7.3%	
	1000 € - 2000 €	8.5%	
	2000 € - 3000 €	20.2%	
	3000 € - 4000 €	12.5%	
	4000 € - 5000 €	10.9%	
	5000 € - 6000 €	8.5%	
	6000 € - 7000 €	2.8%	
	> 7000 €	8.5%	
	Prefer not to answer	17.7%	
			Car availability in Munich
Car availability	Households with no car available	40.3%	409 private cars per 1000 adult inhabitants (40.9%)
	Households with at least one car	59.7%	
			Munich: percent all trips (MVG 2011)
Main transport mode	Private car (driver)	29.4%	31.0%
	Public transportation	59.3%	28.8%
	Bicycle	9.3%	14.7%
	Walk	2.0%	25.5%

Table 4.1 Summary of Sample Characteristics

[14] Percentage of school pupils and students (not gainfully economically active)
[15] Percentage of degree of university of applied sciences and university
[16] Percentage of couples with children
[17] Percentage of one-person households and couples without children
[18] 1 USD = 0.83 Euro (average in 2016)

4.2 Further Insights of the Survey Result

This section gives further insights regarding the survey result, providing relevant information concerning the interpretation of the model results which is presented in Section 5.2. The following subsections contain the analysis results regarding respondents' current travel pattern, choice decisions influenced by respondents' demographic characteristics, description of profile-based demographic characteristics, attitudes stated by different demographics, and the likelihood to choose AFT considering various trip purposes.

Current Travel Pattern

Figure 4.1 reports the share of the current most-frequently-used means of transportation and the corresponding satisfaction levels. It is suggested that respondents are generally satisfied with their current travel patterns in Munich. However, the minority of the respondents who walk or cycling most often are relatively more satisfied than PT users. Interestingly, private car drivers have the lowest satisfaction rate.

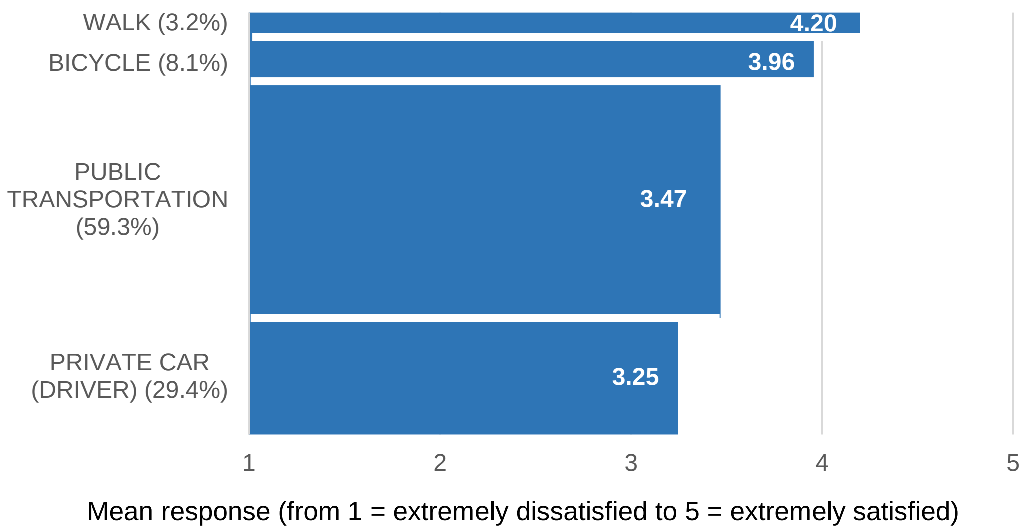


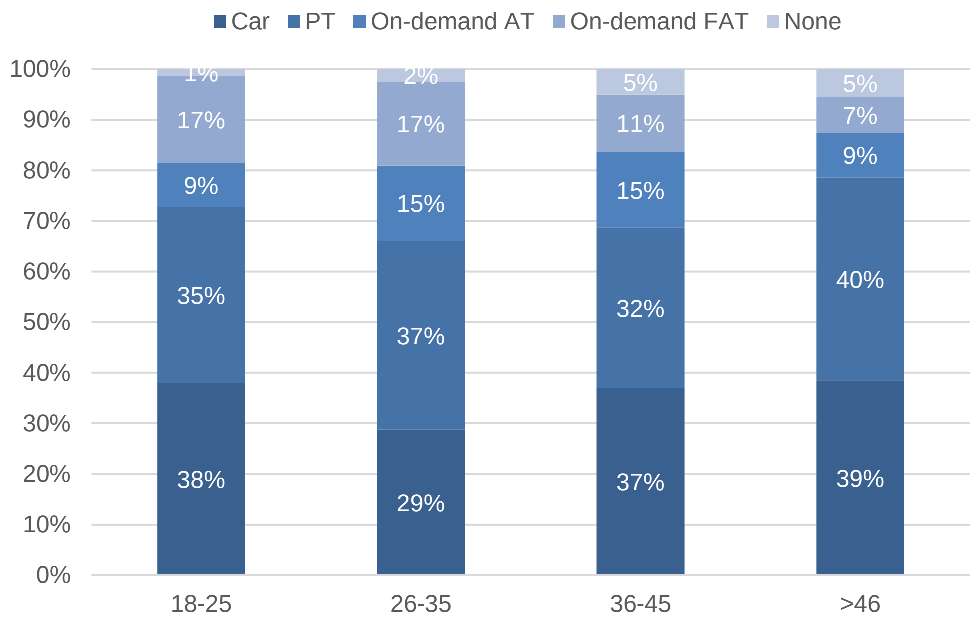
Figure 4.1 Average Satisfaction Rate Stated by the Users of Different Transportation Means

Stated Choice Analysis

Each of the 248 respondents faced twelve choice scenarios, including six scenarios regarding the *commuting trips* purpose, and another six scenarios for the *non-commuting private trips* purpose. Consequently, 2976 were observed based on the combined dataset of *commuting trips* and *non-commuting private trips* scenarios. In total, the alternative private car was observed 1040 times; the alternative PT was selected 1087 times; the alternative AT was chosen 357 times; the alternative AFT was chosen 383 times. Moreover, the *none* option was observed 109 times.

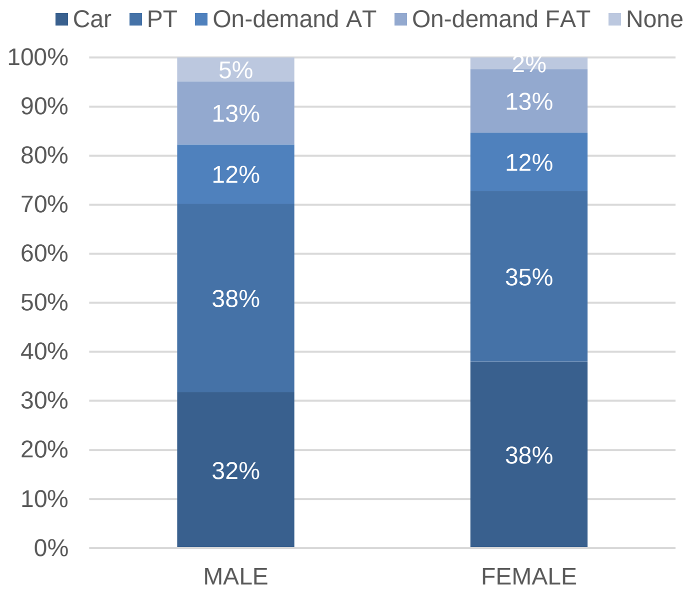
The socio-economic characteristics of the respondents influenced the mode choice decisions. Some examples regarding the impacts of age, gender and income are shown in Figure 4.2 to Figure 4.4, a chi-square test was used to test the independence between the choice attribute and the demographic variables.

A complete demonstration of how other demographic variables affect the choice decisions is attached in Appendix B.



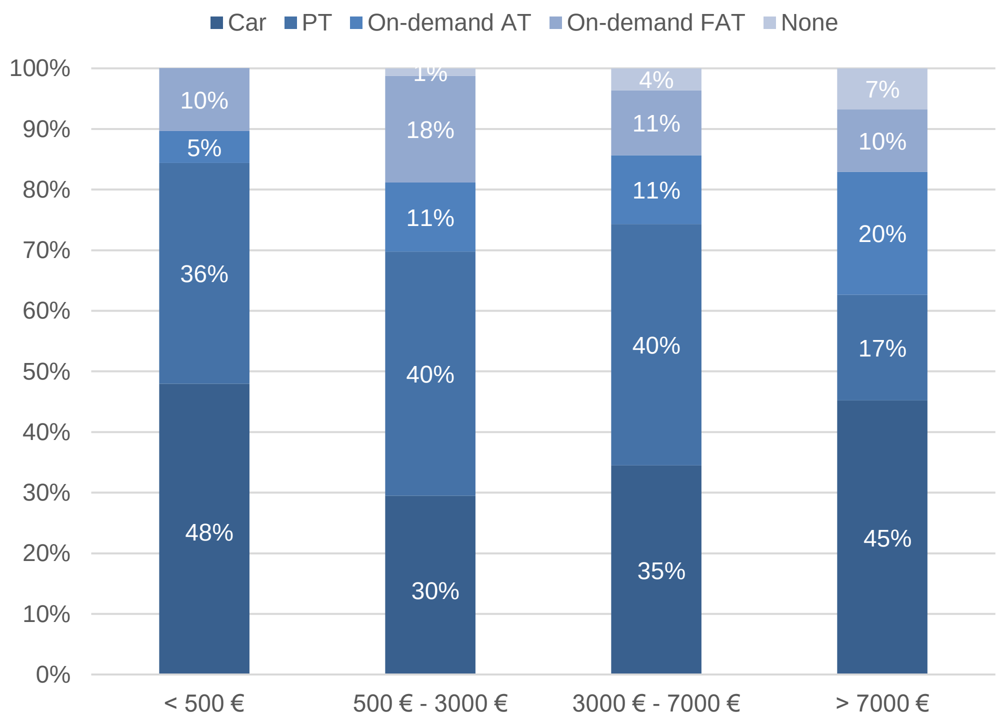
*p < 0.01 regarding within Attribute Chi-Square and between group Chi-Square

Figure 4.2 Mode Choice Decision Influenced by Age



*p < 0.01 regarding within Attribute Chi-Square; P < 0.05 regarding between group Chi-Square

Figure 4.3 Mode Choice Decision Influenced by Gender



*p < 0.01 regarding within Attribute Chi-Square and between group Chi-Square

Figure 4.4 Mode Choice Decision Influenced by Income

Description of Profile-based Demographic Characteristics

A log-linear model was produced to test the mutual independence among the variables age, education level and employment status for the *high-income* group and *low-income* group respectively. The *high-income* (above 7000 €) profile is represented mostly by **older-aged employed** people with **high education level** and **high household income**, as can be seen in Table 4.2. The *low income* (500 € -1000 €) profile is represented mostly by the **younger-aged student** and rather **low income**, as shown in Table 4.3.

Age	Education Level	Employment Status
		Employed people
36 to 45 years old	Master's degree	4.8%
	Ph.D	4.8%
46 to 55 years old	Master's degree	23.9%
	Ph.D	14.3%
56 to 65 years old	Lower than Bachelor's degree	4.8%
	Bachelor's degree	4.8%
	Master's degree	28.6%
Older than 65 years old	Master's degree	14.3%

* $p < 0.05$ for pairwise independence

Table 4.2 Share of High-income Respondents Characterised by Age, Education Level and Employment Status

Age	Education Level	Employment Status	
		Employed people	Student
26 to 35 years old	Lower than Bachelor's degree	-	22.2%
	Bachelor's degree	-	33.3%
	Master's degree	-	11.1%
36 to 45 years old	Lower than Bachelor's degree	5.6%	5.6%
	Bachelor's degree	-	16.7%
	Master's degree	-	5.6%

* $p < 0.05$ for pairwise independence

Table 4.3 Share of Low-income Respondents Characterised by Age, Education Level and Employment Status

Attitudes of Different Demographics

Although the attitudinal variables were not directly involved in the models, the levels of agreement concerning the attitudinal statements were examined for better understanding respondents' choice behaviour. Several results typically reflecting the attitudes associated with demographic characteristics are presented in the following section.

Age

The respondents under all ages stated somewhat positive attitudes towards the new technologies and autonomous transportation modes in general. However, comparing to younger-aged respondents, the respondents aged above 46 years old tend to be less open to trying new technologies, as can be seen in Figure 4.5.

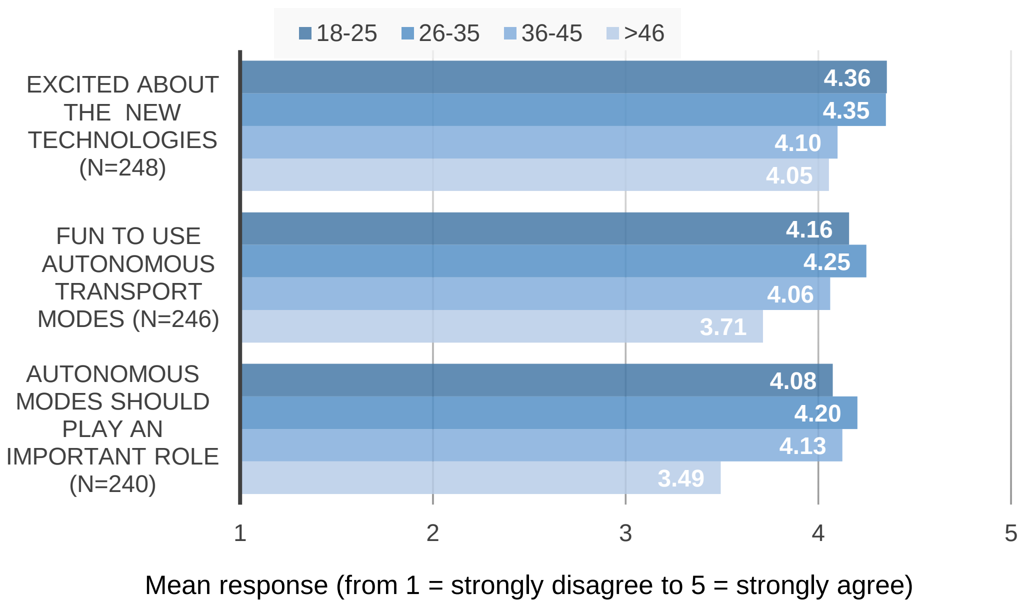


Figure 4.5 Attitudes Associated with Age

Education

The respondents under different education levels stated similar positive attitudes towards the autonomous transportation modes and fairly strong environmental concern. However, it seems that those who are more educated are more willing to accept autonomous transportation modes and willing to pay more for products that are more environmentally friendly, as can be seen in Figure 4.6.

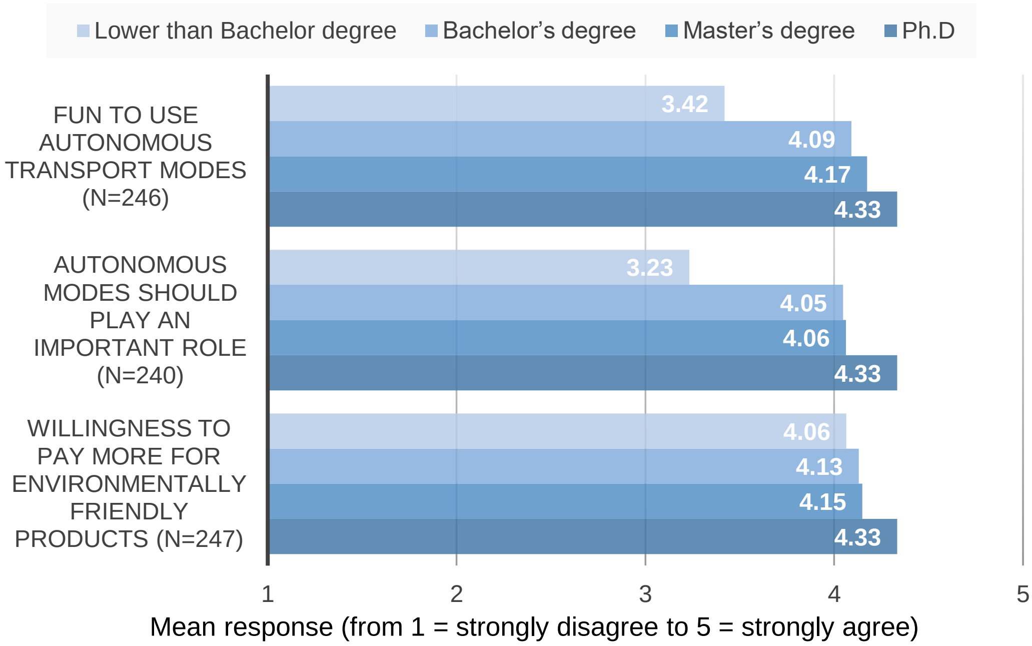


Figure 4.6 Attitudes Associated with Education Level

Income

Figure 4.7 illustrates that the respondents are willing to pay more for environmental-friendly products than for new technological products in general. The respondents with relatively lower household income have low willingness to pay for new technological products, while the "richer" respondents are relatively more willing to spend more on trying new technological products.

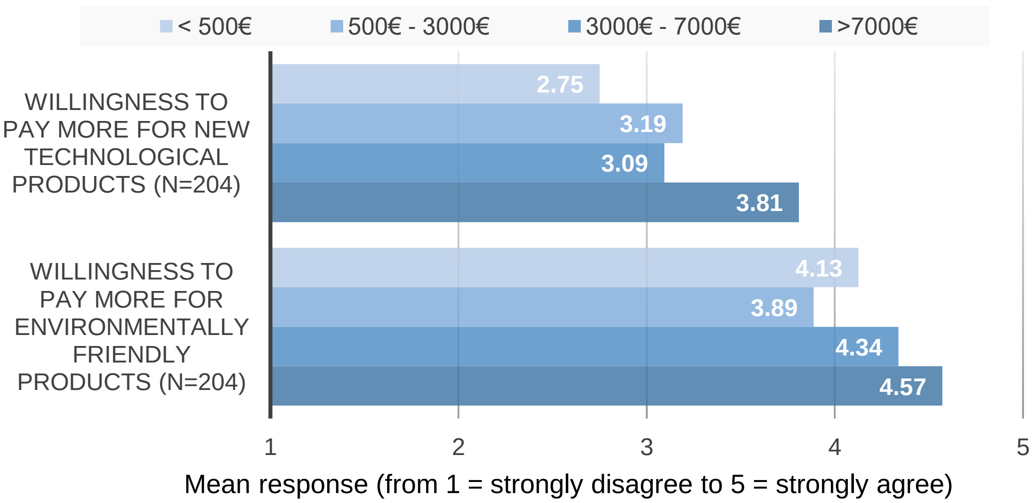


Figure 4.7 Attitudes Associated with Income

Attitudes Towards Autonomous Mode (Based on Gender)

Figure 4.8 demonstrates a generally positive attitude regarding autonomous transportation modes. The further examination indicates that males tend to be more open than females to accepting autonomous transportation modes. Moreover, the overall level of fear regarding autonomous transportation modes is rather low. However, the level of fear to use AFT is higher than using AT for both genders, and females are more afraid than males to try AT and AFT.

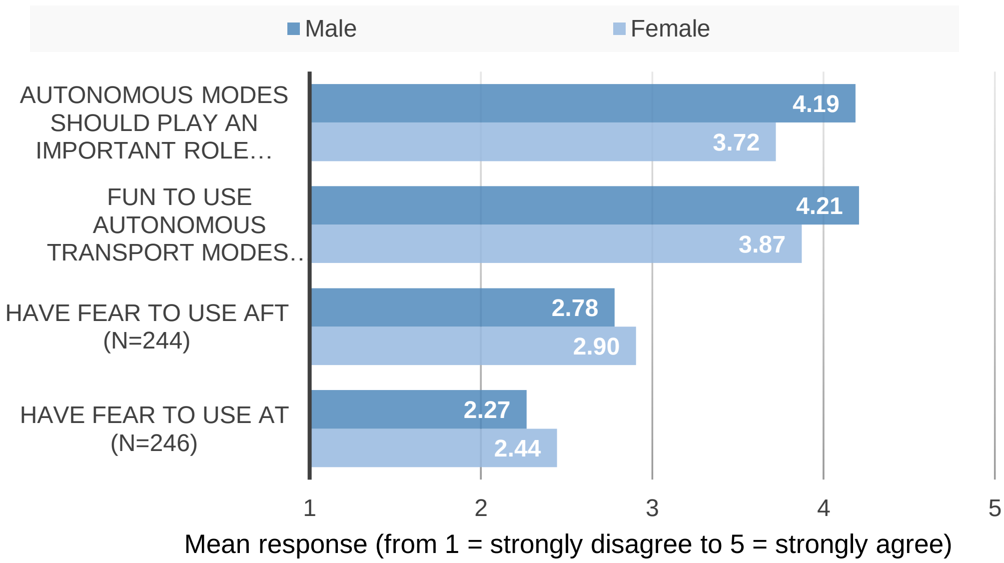


Figure 4.8 Attitudes Associated with Gender

Likelihood of Choosing AFT Regarding Different Trip Purposes

In order to understand the potential usage of AFT, the likelihood to take AFT with regard to various trip purposes has been examined. Figure 4.9 indicates that it is relatively most likely that AFT will be taken to perform business trips, followed by rather high likelihood for performing social and recreational activities. However, for daily commutes such as going to the workplace or universities, as well as for shopping trips, AFT is not likely to be chosen.

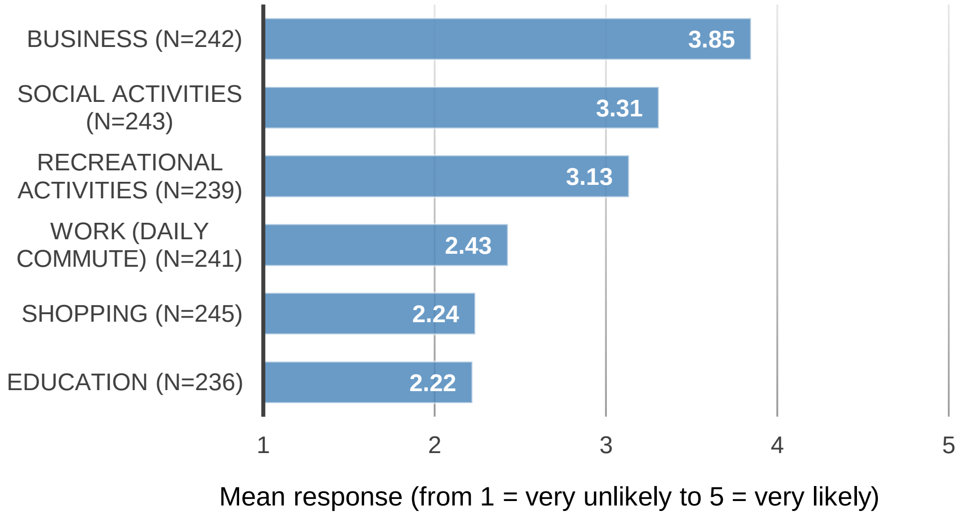


Figure 4.9 Likelihood of Choosing AFT Regarding Different Trip Purposes

5 Results

In this chapter, the model development and its statistical results are firstly presented in Section 5.1, followed by the detailed interpretation of all the coefficients estimated from the relatively robust models.

5.1 Model Development

This section gives a detailed explanation regarding the model development process, corresponding to the model formulation and estimation process described in Section 3.2.2. A list of hypotheses regarding the model performance and several predefined key assumptions against the adoption of UAM is firstly given. The estimated coefficients of different models, as well as the model fit comparisons, are demonstrated in a series of tables.

Expected Outcomes

The models were estimated based on the combined dataset regarding commuting and non-commuting trip purposes. In working towards the goal to obtain a model which can relatively better fit the outcome of the survey, several main hypotheses are formulated:

Hypothesis 1 Demographic characteristics yield significant estimators, and the model fit can be improved by adding these variables.

Hypothesis 2 Involving the choice *none* to the estimation process can improve the MNL model fit.

Hypothesis 3 Mixed logit with panel effect can improve the performance of *high-income profile* model.

Moreover, against the acceptance of UAM services, several assumptions have been made regarding the impacts of the transportation service attributes and the influence of the demographic characteristics of the respondents. The assumptions were made based on the transportation mode choice research review (see Section 2.2) and the *focus group* discussion results. The formulated hypotheses are listed below:

Hypothesis 4 Travel time significantly affects the use of UAM services.

Hypothesis 5 Travel cost significantly affects the use of UAM services.

Hypothesis 6 Waiting time and walking time affect the use of UAM services significantly.

Hypothesis 7 Individuals will adopt the UAM services when AFT can be at least two times safer than driving.

Hypothesis 8 Younger-aged individuals are relatively more likely to adopt UAM services.

Hypothesis 9 Individuals with high income are relatively more likely to adopt UAM services.

Hypothesis 10 Males are relatively more likely to adopt UAM services.

Hypothesis 11 Individuals with lower education levels are relatively less likely to adopt UAM services.

Hypothesis 12 Individuals with children (0 to 17 years old) living in the households are relatively more likely to adopt UAM services.

Hypothesis 13 Individuals with car available in the households are relatively more likely to adopt UAM services.

Hypothesis 14 Individuals who travel by car as driver most frequently are relatively more likely to adopt UAM services.

Hypothesis 15 UAM services are relatively less likely to be used for daily commutes.

MNL

The MNL models excluding and including the choice *none* have been firstly estimated respectively. The estimation procedure started from including the ASCs and the attributes of travel time and travel cost. Except for the ASC of the private car, all coefficients were found to be significant, and the signs were as expected. The specification of utility functions per mode, including the *none* parameter, is presented by Equation 5.1 to 5.5. The estimated coefficients are listed in Table 5.1.

$$V_{CAR} = \beta_{TT_{CAR}} * TT_{CAR} + \beta_{COST_{CAR}} * COST_{CAR} \quad (5.1)$$

$$V_{PT} = ASC_{PT} + \beta_{TT_{PT}} * TT_{PT} + \beta_{COST_{PT}} * COST_{PT} \quad (5.2)$$

$$V_{AT} = ASC_{AT} + \beta_{TT_{AT}} * TT_{AT} + \beta_{COST_{AT}} * COST_{AT} \quad (5.3)$$

$$V_{AFT} = ASC_{AFT} + \beta_{TT_{AFT}} * TT_{AFT} + \beta_{COST_{AFT}} * COST_{AFT} \quad (5.4)$$

$$V_{NONE} = \beta_{NONE} * NONE \quad (5.5)$$

with

V_m : utility of transportation mode m

ASC_m : alternative-specific constant of transportation mode m

β_{TT_m}: coefficient of total travel time for transportation mode m

β_{COST_m}: coefficient of travel cost for transportation mode m

β_{NONE}: the constant of *none* alternative

Utility coefficient: estimated value [robust t-test]; significant values are marked by * (robust p-value < 0.05) and ** (robust p-value < 0.01)									
	MNL (*none* alternative excluded)				**MNL (*none* alternative included)**				
Coefficient	**Car**	**PT**	**AT**	**AFT**	**Car**	**PT**	**AT**	**AFT**	**None**
ASC	-	Base case	1.42*[2.77]	-2.76**[-6.51]	-	Base case	1.39*[2.76]	-2.63**[-7.85]	-5.75**[-31.17]
Travel cost	-1.55**[-8.03]	-1.16**[-5.36]	-2.02**[-5.39]	-0.47**[-9.73]	-1.62**[-8.46]	-1.19**[-5.63]	-2.00**[-5.39]	-0.46**[-9.72]	-
Total travel time	-0.85**[-20.47]	-0.64**[-18.49]	-1.07**[-13.42]	-0.32*[-2.10]	-0.84**[-20.49]	-0.64**[-18.89]	-1.07**[-13.52]	-0.33*[-2.13]	-
Model information									
Sample size	2867				2976				
Number of estimated parameters	10				11				
Initial log-likelihood	-3974.506				-4789.687				
Final log-likelihood	-2946.200				-3412.962				
Adjusted rho square	0.256				0.285				

Table 5.1 Estimated Coefficients and Model Information for MNL Models including ASC, Travel time and Travel cost

After the model estimation containing ASC, travel time and travel cost, the socio-demographic attributes were then added and estimated. The specification of the utility functions per mode (alternative), as well as the notations, can be found in Appendix C-2 and Appendix C-3.

Although models with different sample size cannot be compared directly based on the statistical test, after examining the increase of the log-likelihood of two models as well as the magnitudes and significance of the coefficients, the MNL model with *none* choice seems to estimate better the data, with the adjusted rho square 0.364, compared to 0.327 of MNL with *none* choice excluded. This result leads to the retention of *Hypothesis 2* (Involving the choice *none* to the estimation process can improve the MNL model fit. See Table 5.2).

The estimated utilities of two models are presented in with the robust t-test in Table 5.2. Only parameters that are significant at a 95 % level are included in the model, except for some special cases which will be explained in Section 5.2.

Moreover, the model estimation results shown in Table 5.1 and Table 5.2 indicate that the inclusion of demographics attributes has improved the model and thus retain the *Hypothesis 1* (Demographic characteristics yield significant estimators, and the model fit can be improved by adding these variables.) as well.

Utility coefficient: estimated value [robust t-test]; significant values are marked by * (robust p-value < 0.05) and ** (robust p-value < 0.01)

□ :Coefficients that are constrained to be the same when there is no significant difference

	MNL (*none* alternative excluded)				MNL (*none* alternative included)				
Coefficient	**Car**	**PT**	**AT**	**AFT**	**Car**	**PT**	**AT**	**AFT**	**None**
ASC	-	Base case	1.19*[2.02]	-2.76**[-6.51]	-	Base case	1.37*[2.34]	-2.92**[-7.11]	-6.91**[-24.25]
Travel cost	-1.91**[-8.14]	-1.61**[-6.59]	-2.03**[-5.08]	-0.48**[-9.42]	-1.96**[-8.47]	-1.66**[-6.91]	-2.10**[-5.25]	-0.47**[-9.50]	-
Total travel time	-0.923**[-19.00]	-0.74**[-15.59]	-1.13**[-13.10]	-0.36*[-2.18]	-0.90**[-18.86]	-0.76**[-16.25]	-1.14**[-13.16]	-0.35*[-2.16]	-
Safety (reference = driving level safety)									
At least two times safer than driving	-	-	0.291*[2.01]	-	-	-	0.26[1.90]	-	-
Two times riskier than driving	-	-	-0.350*[-2.16]	-0.298*[-2.21]	-	-	-0.36*[-2.21]	-0.26[-1.94]	-
Inconvenience indicated by walking and waiting time	-	-0.87**[-4.86]	-	-	-	-0.86**[-4.89]	-	-	-
Age (reference = 18-45)									
46-55	-	Base case	-1.10**[-8.71]	-1.10**[-8.71]	-	Base case	-1.12**[-8.93]	-1.12**[-8.93]	-
56-65	-0.612**[-3.81]	Base case	-1.10**[-8.71]	-1.10**[-8.71]	-0.70**[-4.39]	Base case	-1.12**[-8.93]	-1.12**[-8.93]	-
> 65	-1.80**[-5.11]	Base case	-	-1.80**[-5.11]	-1.69**[-4.19]	Base case	-	-1.74**[-3.09]	-7.65**[-29.37]
Gender (reference = female)									
Male	-	-	-	-	-0.21*[-2.24]	Base case	-	-	-
Employment (reference = working people)									
Student	0.627**[4.29]	Base case	-	0.809**[4.34]	0.61**[4.24]	Base case	-	0.74**[4.63]	-
Others	0.468*[2.66]	Base case	-	-	0.45*[2.52]	Base case	-	-	-
Presence of children (0-17 years old) in the household (reference = no)									
Yes	-	-	-	-	-	Base case	-	-	1.04**[5.25]
Car availability (reference = yes)									
No	-0.84**[-6.51]	Base case	-0.49**[-2.88]	-1.10**[-6.22]	-0.85**[-6.69]	Base case	-0.79**[-5.46]	-0.79**[-5.46]	-
Current means of transport (reference = car as driver)									
PT	-1.63**[-10.62]	Base case	-1.44**[-8.92]	-1.44**[-8.92]	-1.64**[-11.38]	Base case	-1.50**[-9.63]	-1.50**[-9.63]	-2.97**[-9.54]
Soft modes inc. cycling and walking	-1.47**[-7.58]	Base case	-1.27**[-4.91]	-1.74**[-6.43]	-1.64**[-11.38]	Base case	-1.43**[-6.04]	-1.99**[-7.48]	-
Trip purpose (reference = non-commuting private trip)									
Commuting trip	-0.35**[-3.34]	Base case	-0.40**[-2.91]	-0.71**[-5.14]	-0.39**[-3.79]	Base case	-0.45**[-3.23]	-0.72**[-5.34]	-
Monthly household income (reference = 3000€ - 6000€)									
<500€	0.57*[2.06]	Base case	-	-	0.62*[2.25]	Base case	-	-	-6.98**[-23.44]
500€ - 1000€	-	Base case	0.60*[2.46]	0.84**[3.12]	-	Base case	0.75**[3.74]	0.75**[3.74]	-
1000€ - 2000€	-	Base case	-	0.64*[2.68]	-	Base case	-	0.50*[2.24]	-
2000€ - 3000€	-	Base case	-	0.58**[3.74]	-	Base case	-	0.52**[3.41]	-1.37**[-3.17]
6000€ - 7000€	-	Base case	-	-1.10*[-2.14]	-	Base case	-	-1.05*[-2.03]	1.58**[3.15]
>7000€	0.81**[3.51]	Base case	1.32**[4.99]	0.69*[2.28]	0.86**[3.81]	Base case	1.30**[4.97]	0.79*[2.62]	0.67*[2.14]
Model information									
Sample size	2867				2976				
Number of estimated parameters	40				47				
Initial log-likelihood	-3974.506				-4789.687				
Final log-likelihood	-2634.530				-2996.902				
Adjusted rho square	0.327				0.364				

Table 5.2 Estimated Coefficients and Model Information for MNL Models

Profile-based MNL and ML

According to the results estimated based on MNL, *high-income* (above 7000 €) group as well as the lower income group, was found relatively more likely to have the propensity to use AFT. Therefore, it was decided to investigate further and describe the potential users using *profiles*. Based on the results of exploratory analysis regarding respondents' demographic characteristics (Section 4.2), two profiles, namely *high-income profile* and *lower-income profile* were defined.

To describe the *high-income* users' choice behaviour, only respondents with income higher than 7000 € per month were examined, amounting to 8 % of the sample. Similar to the procedure of estimating the MNL models, two profile-based MNL models excluding and including the choice of *none* were firstly estimated respectively.

Moreover, an ML model with panel effects was attempted to apply regarding the *high-income profile*. To simplify the model estimation, the panel effect is introduced only to the ASCs, meaning that the ASCs in the utility function vary across individuals but are constant over the choice situations for each individual (Haboucha et al., 2017). The distribution of the coefficients is specified to be normally distributed, and the parameters of the normal distribution are estimated (Haboucha et al., 2017).

Regarding the specification of the models mentioned above, the procedure of starting from one parameter and adding the rest of them was followed here as well. The specification of the utility functions per mode (alternative) for each model, as well as the notations, can be found in Appendix C-4 to Appendix C-8.

Comparing three models designed to analysing the *high-income profile*, the *high-income profile*-based MNL model excluding the *none* choice (with adjusted rho square 0.460), was found relatively acceptable based on the current result. However, this illustrative example is not possible to either reject or retain the *Hypothesis 3* (Mixed logit with panel effect can improve the performance of *high-income profile* model. See Table 5.3), since the estimation of ML model was only made with ASC and one distributional assumption. It may be worth to allocate a good proportion of time to investigate with more attributes and the possibility of different distributional assumptions for each attribute (Hensher et al., 2015, p. 611).

The estimated utilities of *high-income profile* models are presented in with the robust t-test in Table 5.3, with only parameters that are significant at a 95 % level.

Utility coefficient: estimated value [robust t-test]; significant values are marked by * (robust p-value < 0.05) and ** (robust p-value < 0.01) ▭ :Coefficients that are constrained to be the same when there is no significant difference														
	***High-income profile* MNL (*none* alternative excluded)**				***High-income profile* MNL (*none* alternative included)**					***High-income profile* ML (*none* alternative included)**				
Coefficient	**Car**	**PT**	**AT**	**AFT**	**Car**	**PT**	**AT**	**AFT**	**None**	**Car**	**PT**	**AT**	**AFT**	**None**
ASC	3.20**[2.91]	Base case	4.76**[3.69]	-	-	-	-	-	-	6.16**[8.33]	Base case	6.16**[8.33]	6.16**[8.33]	6.16**[8.33]
Travel cost	-2.50*[-2.65]	-	-	-0.99**[-4.87]	-	-	-	-0.55**[-5.01]	-	-2.00*[-2.42]	-	-	-1.96**[-5.69]	-
Total travel time	-1.17**[-7.05]	-0.92**[-6.02]	-2.25**[-5.87]	-	-1.03**[-5.86]	-	-0.80**[-3.43]	-	-	-0.97**[-6.97]	-	-1.64**[-7.97]	-	-
Safety (reference = driving level safety)														
At least two times safer than driving	-	-	-	-	-	-	1.88**[3.78]	-	-	-	-	1.04*[2.59]	-	-
Two times riskier than driving	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Age (reference = 18-45)														
46-55	1.11*[2.80]	Base case	-	-	1.26**[3.00]	Base case	-	1.57**[3.13]	-	0.90*[2.72]	Base case	-	-	-
56-65	2.42*[2.62]	Base case	2.51**[3.08]	2.51**[3.08]	-	Base case	-	2.82**[4.27]	-	-	-	-	-	-
> 65	-	-	-	-										
Gender (reference = female)														
Male	-	-	-	-	-1.00*[-2.49]	Base case	-2.62**[-4.08]	-	-	-	-	-	-	-
Education level (reference = Bachelor)														
Lower than Bachelor	-	-	-	-	5.12**[3.80]	Base case	-	-	-	-	-	-	-	-
Master	-	-	-	-	5.65**[7.86]	Base case	4.27**[4.91]	-	-	-	Base case	-	-	-0.57*[-1.98]
PhD	-	-	-	-	4.60**[5.63]	Base case	-	-	-	-	Base case	-	-2.64**[-3.03]	-2.59*[-2.46]
Presence of children (0-17 years old) in the household (reference = no)														
Yes	-	Base case	-	-1.99**[-3.35]	-1.24**[-3.48]	Base case	-	-	-2.00**[-3.30]	-0.67*[-2.08]	Base case	-	-2.95**[-4.29]	-
Car availability (reference = yes)														
No	-	Base case	5.16**[4.24]	-	-	Base case	9.86**[6.26]	-	-	-	-	-	-	-
Current means of transport (reference = car as driver)														
PT	-2.56**[-4.77]	Base case	-2.18**[-4.16]	-2.18**[-4.16]	-1.14*[-2.67]	Base case	-	-1.75**[-3.14]	-	-1.73**[-4.26]	Base case	-	-	-
Soft modes inc. cycling and walking	-2.28**[-2.91]	Base case	-	-	-	Base case	-	-	3.69**[4.67]	-2.47**[-3.26]	Base case	-	-	-
Interaction between monthly household income and commuting trip purpose (reference = Interaction between *more than 7000€* and *non-commuting trip purpose*)														
>7000€ x commuting trip	-1.33**[-2.99]	Base case	-1.33**[-2.99]	-1.33**[-2.99]	-	-	-	-	-	-	Base case	-1.08**[-3.24]	-1.08**[-3.24]	-
Model information														
Number of draws	-				-					500				
Random coefficient	-				-					0.01[1.38]				
Sample size	235				252					252				
Number of estimated parameters	16				19					16				
Initial log-likelihood	-325.779				-405.578					-405.578				
Final log-likelihood	-160.078				-230.432					-239.588				
Adjusted rho square	0.460				0.385					0.370				

Table 5.3 Estimated Coefficients and Model Information for *High-income Profile* Models

When analysing the *lower-income profile*, respondents with the monthly household income between 500 € and 3000 € were examined, amounting to 46 % of the sample. For this model, a better model fit was attained by including the *none* option to the *lower-income profile* MNL model (with adjusted rho square 0.393 and increase of log-likelihood 906.495), compared with the model excluding the *none* choice (with adjusted rho square 0.336 and increase of log-likelihood 642.092).

The estimated utilities of *lower-income profile* models are presented in with the robust t-test in Table 5.4, with only parameters that are significant at a 95 % level.

Utility coefficient: estimated value [robust t-test]; significant values are marked by * (robust p-value < 0.05) and ** (robust p-value < 0.01)
▭ :Coefficients that are constrained to be the same when there is no significant difference

	***Lower-income profile* MNL (*none* alternative excluded)**				***Lower-income profile* MNL (*none* alternative included)**				
Coefficient	**Car**	**PT**	**AT**	**AFT**	**Car**	**PT**	**AT**	**AFT**	**None**
ASC	3.30**[6.54]	Base case	-	-	2.33**[4.43]	Base case	2.73**[3.19]	-	-9.66**[-7.77]
Travel cost	-2.60**[-6.70]	-	-	-0.79**[-6.23]	-2.40**[-6.48]	-1.32**[-3.69]	-1.95**[-3.42]	-0.61**[-6.20]	-
Total travel time	-1.07**[-13.93]	-0.64**[-11.75]	-0.91**[-13.08]	-	-0.98**[-13.33]	-0.68**[-10.46]	-1.17**[-9.66]	-0.95**[-4.77]	-
Safety (reference = driving level safety)									
At least two times safer than driving	-	-	0.52**[2.94]	-	-	-	0.38*[2.07]	-	-
Two times riskier than driving	-	-	-	-	-	-	-	-	-
Age (reference = 36-45)									
18-25	-	-	-	-	0.78**[3.53]	Base case	-	1.47**[4.71]	-
26-35	-	-	-	-	-	Base case	-	0.73**[3.06]	-
46-55	0.41*[2.17]	Base case	-	-0.81**[-3.11]	0.55**[3.12]	Base case	-	-	-
56-65	-	Base case	-	-0.73*[-1.99]	-	Base case	-	-	2.49**[4.80]
>65	-	-	-	-	-	-	-	-	-
Gender (reference = female)									
Male	-0.40*[-2.78]	Base case	-	-	-0.42**[-3.12]	Base case	-	-	-
Employment (reference = working people)									
Student	0.52*[2.29]	Base case	-	-	-	-	-	-	-
Others	-	-	-	-	-	-	-	-	-
Education level (reference = Bachelor)									
Lower than Bachelor	-	Base case	-	-1.12**[-2.99]	-	Base case	-	-1.04*[-2.47]	-
Master						Base case			3.27**[3.61]
PhD									
Presence of children (0-17 years old) in the household (reference = no)									
Yes	-	-	-	-	-	Base case	-	-	2.17**[5.04]
Car availability (reference = yes)									
No	-1.20**[-6.43]	Base case	-0.73**[-2.97]	-0.76*[-2.74]	-1.11**[-6.05]	Base case	-0.79**[-3.21]	-0.68*[-2.34]	-
Current means of transport (reference = car as driver)									
PT	-1.13**[-5.40]	Base case	-0.99**[-4.17]	-1.98**[-7.93]	-1.23**[-6.47]	Base case	-1.23**[-6.47]	-2.24**[-7.80]	-2.35**[-5.26]
Soft modes inc. cycling and walking	-1.50**[-4.98]	Base case	-1.27**[-3.15]	-2.92**[-5.51]	-1.54**[-5.49]	Base case	-1.54**[-5.49]	-2.83**[-4.92]	1.79**[3.63]
Trip purpose (reference = non-commuting private trip)									
Commuting trip	-0.37*[-2.57]	Base case	-	-0.72**[-3.70]	-0.49**[-3.22]	Base case	-0.41*[-2.09]	-0.71**[-3.34]	-
Model information									
Sample size	1326				1380				
Number of estimated parameters	24				33				
Initial log-likelihood	-1838.226				-2221.024				
Final log-likelihood	-1196.134				-1314.529				
Adjusted rho square	0.336				0.393				

Table 5.4 Estimated Coefficients and Model Information for *Lower-income Profile* Models

Remark About NL

The attempt was made to estimate NL models with four different nested structures:

- *Real alternatives* (car, PT, AT, AFT) or *Choose none of them* (none)
- *Autonomous modes* (AT, AFT) or *Non-autonomous modes* (car, PT) or *Choose none of them* (none)
- *Ground modes* (car, PT, AT) or *Flying mode* (AFT) or *Choose none of them* (none)
- *Privately owned mode* (car) or *Shared modes* (PT, AT, AFT) or *Choose none of them* (none)

However, unfortunately, the model estimation did not succeed, due to some unexpected errors which led to the unidentifiable models. Further research may be required regarding analysing the errors. Moreover, further attempts could be made on improving the nested structures, for example, to establish two-level (multi-level) structures, including the choice of the nest as one level, and the choice of alternative within the nest as another.

5.2 Interpretation of Estimated Model Coefficients

The following section interprets the estimated model coefficients shown in Table 5.2 to Table 5.4 of Section 5.1.

MNL

Based on the MNL with *none* choice, the following direct observation can be made concerning transportation service attributes and demographic attributes.

Transportation Service Attributes

When reading the estimated ASCs which capture the average effect on the utility of all factor that is not included in the model, the significant coefficients indicate that the AT is the most preferred mode, followed by PT and car, while the AFT is found rather unattractive among four transport alternatives. In terms of **travel times** and **travel costs**, all coefficients were found to be statistically significant and show an expected negative sign. Regarding the utility of **safety levels**, the coefficient of *riskier than driving-level-safety* level is significant and has the expected negative signs with respect to the reference level which represents the *driving-level-safety*. However, no significant coefficients could be estimated for the level of *safer than driving-level-safety* concerning AT and AFT, although the *safer than driving* coefficient for AT shows an expected positive sign and has the robust t-test of 1.88. Moreover, it was decided to keep the *safer then driving-level-safety* parameter for AT because it is significant in the MNL model with *none* choice excluded. Nevertheless, the estimated coefficients for **waiting and/or walking time** parameters were proved to be insignificant for all the alternatives except for PT.

Demographic Attributes

In terms of the relationship between **age** and the propensity to use the autonomous modes, a significant result is revealed for individuals aged between 46 and 65 years old, who are relatively less likely to choose any of the autonomous modes, followed by the car, while PT is the most preferred mode. Whereas for individuals above 65 years old, the AFT is preferred over the private car, while still, both are less desirable compared to PT and AT. Moreover, it must be noted here that the age between 18 and 35 have non-significant coefficients and thus are equally the base level. Therefore, the reference level of age variables was set to 18 to 45 years old.

Similar to how reference level of age was handled, the coefficients of **income** level *between* 4000 € and 6000 € are non-significant and thus are equally the original base level (3000 € to 4000 €). The reference level of income is therefore defined as 3000 € to 6000 €. Regarding how income may affect the mode choice, individuals with the monthly household income level of 500 € to 1000 € and above 7000 € show a relatively keen interest in using autonomous modes. Especially people with above 7000 € monthly income find AT most attractive. Moreover, the significant coefficients with positive signs also reveal the possible propensity to use AFT for individuals having household income between 1000 € to 3000 €.

Concerning the **employment status**, the *students* are more likely to have a higher interest in using AFT than using conventional transport modes and AT. For employment status other than employed and student, no significant coefficients could be estimated for the preference of autonomous modes, but the coefficient on choosing car alternative shows that car is likely to be the most preferred mode.

Furthermore, the significant results also indicate a relationship between individual's propensity to switch to autonomous modes and individual's car availability, currently-used travel modes, and trip purpose, respectively. More specifically, respondents with no **car available** in the household find the PT the most attractive transport mode in Munich, but they tend to prefer autonomous modes over the private car. Meanwhile, compared with individuals with *car available* in the households, individuals with *no car available* are likely to have lower propensity to use both autonomous modes. The **current PT users** are relatively less likely to switch to the option AT or AFT from PT, but the private car is found least attractive for them. And for **current soft mode (walking or cycling) users**, PT is also more likely to be chosen, followed by AT and private car, while switching to AFT is not relatively more likely. Moreover, for the commuting **trip purpose**, PT is seen as the most desirable alternative, followed by the private car, and individuals are relatively less open to use hypothetical autonomous modes, especially the AFT, comparing to the choice regarding non-commuting private trips,

In addition, the coefficients on the attributes of gender, education level and presence of children in the household did not allow for inferences about how autonomous modes may be adopted. The statistically significant relationship is only revealed for respondents with **children** (between 0 and 17 years old) living in the household, who are relatively more likely to use AFT than respondents without children living in the households and may prefer the alternative AFT over the other alternatives.

Profiles-based MNL

High-income Profile

Among this group, in terms of the impact of **age**, a strong relationship between individuals aged *56 to 65 years old* and their propensity to use autonomous transportation modes is suggested by the result. However, for *high-income* respondents aged between 46 and 55 years old, the only significant result shows that they are more likely to prefer car over the other alternatives.

Some other significant coefficients were also obtained. One of them suggested that the respondents belonging to this group and having **children** may have lower propensity to use AFT than those without children and are relatively less likely to choose AFT comparing to other options. Concerning the impact of **car availability**, individuals without car available in the household are likely to have a relatively stronger propensity to use AT. In terms of the current means of transport, the results again prove that **current PT users** are less likely to switch to any other transport alternatives, whereas for **current soft mode users**, the private car seems like the least attractive mode among four alternatives. In addition, the interaction between income attribute and the **trip purpose** attribute is found significant and again prove that PT is the most likely alternative to be selected regarding the commuting trips.

For the *high-income profile* investigated, not all the transportation-related attributes are significant. The estimated ASCs indicate that AT is the relatively most desirable option, followed by the private car, while PT and AFT are less likely to be selected. The estimated coefficients on **travel times** measures are significant and have expected signs for the car, PT and AT, while only coefficients of **travel costs** regarding car and AFT are found to be significant. However, no significant estimators could be found concerning **safety** and **inconvenience** parameters.

Lower-income Profile

Regarding the **age** characteristics of this group, the significant estimation results indicate a connection between individuals aged 18 to 35 years old and their preference regarding AFT over the other alternatives. Moreover, the younger respondents aged 18 to 25 years old are more likely than the respondents aged 26 to 35 years old to find AFT more attractive. Regarding the age group of 46 to 55 years old, the only significant coefficient indicates that the private car may be preferred over the other modes. While for the individuals aged between 56 and 65 years old, no significant coefficients could be estimated except for that of *none* option, which indicates that people of this age group may prefer some other transport alternatives which are not included in the provided choice set.

Some other socio-economic and family-status estimators that are found significant regard gender, education level and presence of children in the household. In terms of the impact of **gender**, males belonging to this group tend to find the private car least attractive compared to all the other options. Meanwhile, individuals with the **education** level lower than Bachelor degree tend to least favour AFT among all the choices. And for individuals holding a Master degree, some other alternatives may be more attractive than the available options, and a similar result is shown regarding individuals having **children** in the household.

Furthermore, other attributes including car availability, currently-used transport modes, as well as trip purpose were found to have a relatively significant impact. For individuals do not have a **car available**, PT is the option that is most likely to be selected, followed by AFT, AT, and private car. Current **PT users** may have the similar attitudes towards the private car and AT, but switching to AFT seems relatively unlikely. Regarding the **soft mode users**, AFT is likely to be the least attractive transport alternative, followed by car and AT, and these users may either find none of the available choices is desirable to use or expect other alternatives to be provided. In terms of the choice decision based on **trip purposes**, PT may be regarded as the most feasible transport mode for daily commutes, followed by AT and car. However, the AFT option seems relatively least likely to be selected on trips for commuting.

For the *lower-income profile* examined, the significant ASCs suggest that AT is likely to be more attractive than car, followed by PT and AFT. The estimated coefficients on **travel times** and **travel costs** measures are statistically significant and show an expected negative sign. Regarding the utility of **safety** levels, only the coefficient of *safer than driving-level-safety* level is significant and has the expected positive sign for AT. Nevertheless, the estimated coefficients for **waiting and/or walking time** parameters were proved to be insignificant for all the alternatives.

6 Discussion of Main Findings

The following sections conclude and discuss the results from two main perspectives – transportation service attributes (Section 6.1) and policy implication (Section 6.2).

6.1 Discussion of Transportation Service Attributes

The following section summarises and discusses the findings regarding the transportation service attributes including travel time, travel cost and safety level, as well as the calculation results of a policy indicator VOT. Meanwhile, survey comments from the respondents were examined and listed to further explain the findings.

Travel Time and Travel Cost Components

In terms of the main trend, travel costs play a smaller role than travel times. Among the travel time components, the total travel time shows the most influential impact, while the walking time and/waiting time shown to have no significant impact only on the utility of AT and AFT. Regarding AT, this may be interpreted as a difference in the perception of waiting time in case of ODM door-to-door service as opposed to waiting and walking time of using scheduled PT services (Winter et al., 2017). However, the unexpected result regarding AFT may be explained by the issues of SP choice experiment as well as the respondents' misinterpretations about the settings of travel time components.

By examining the survey comments received, some misunderstandings regarding the issues mentioned above were noticed. In order to further explain the problems, two comments (1 and 2) are presented as examples as follows:

1. *„Auch verstand ich die Hypothese nicht, daß autonomes Fahren so viel mehr Zeit in Anspruch nimmt, wie eigenses* [*sic*] *Fahren. Dies machte mir eine echte Auswahl schwer.“*
   [Translation: I also did not understand the hypothesis that autonomous driving takes much more time than own driving. This made it difficult for me to make a real choice.]

The respondent found it difficult to make a real choice because he or she did not notice that the waiting times are included as part of the total travel time, and thus lead to longer total travel time to use AT than driving.

2. *„Leider missverständlich: Sind die zusätzlichen, in Zeit umgerechneten Kosten für Unbequemlichkeit schon in der Gesamtreisezeit enthalten oder noch draufzurechnen???“*
   [Translation: Unfortunately misleading: Are the additional costs for inconvenience, converted into time, already included in the total travel time or can they be added to it?]

This case shows that the respondent was uncertain about whether the waiting times and walking times are included in the total travel times.

The misinterpretations mentioned above could be caused by the artificial nature of SP choice experiment. According to Baxter & Brumfitt (2008), in the SP choice experiment, some attributes might receive less attention than they should to simplify the choice task, and therefore, If cost and time are more significant to choice, then the importance of other attributes might be understated in relation to them.

Therefore, based on the outcome mentioned above, it is suggested that *Hypothesis 4* (Travel time significantly affects the use of UAM services. See Table 5.2) and *Hypothesis 5* (Travel cost significantly affects the use of UAM services. See Table 5.2) can be retained. However, before the misinterpretations regarding the waiting times and walking times get clarified, it may not be possible either to reject or to retain *Hypothesis 6* (Waiting time and walking time significantly affects the use of UAM services. See Table 5.2).

Calculation of VOT

VOT presents the marginal rate of substitution between time and money in the conditional indirect utility function, as seen in Equation 6.1.

$$(\mathrm{v_T})_{\mathrm{iq}} \equiv -(\frac{\mathrm{dC_{iq}}}{\mathrm{dT_{iq}}})_{\mathrm{V_{iq}}} \equiv \frac{\partial \mathrm{V_{iq}}/\partial \mathrm{T_{iq}}}{\partial \mathrm{V_{iq}}/\partial \mathrm{C_{iq}}} \tag{6.1}$$

where

V_{iq}: systematically derived element of the i^{th} alternative for individual q

C_{iq}: travel costs,

T_{iq}: travel times.

(Small, 2012)

VOT analysis is an important indicator of travel behaviour models which gives the willingness to pay of the respondents in case of a reduction in the travel time by one hour (Atasoy et al., 2006). Table 6.1 shows the VOT values calculated based on the statistically significant estimated total travel time and travel cost parameters, without differentiating the trip purposes, based on the MNL model.

Transportation Modes	VOT (Euros/hour)
Private car	27.55
Public transportation	27.47
Autonomous taxi	32.57
Autonomous flying taxi	44.68

Table 6.1 Calculation of VOT

Among the factors having an impact on VOT, an increase in income leads to an increase in the value of travel time (Wardman & Chintakayala, 2012). As the undisputed economic leader in Germany, Munich's labour productivity, as well as the average income level significantly surpasses the levels of other German cities (Euromonitor International, 2017). This may lead to the relatively higher VOT results, comparing to some findings shown in Table 6.2 concerning the average German VOT reported by Wardman, Chintakayala, & Jong (2016), which illustrates the official VOT based on national studies compared with EIB (European Investment Bank) values and meta-model values provided by Wardman et al. (2016).

	Commute			Other			Business		
	Official	Meta	EIB	Official	Meta	EIB	Official	Meta	EIB
Germany									
Car	5.95	7.98	9.42	5.95	6.53	6.68	33.44	21.58	31.39
Train	5.95	6.46	10.14	5.95	5.53	7.12	23.88	20.05	30.01
Bus	5.95	3.89	9.31	5.95	3.56	6.14	25.72	13.62	28.50
Switzerland									
Car	31.73	12.29	12.14	23.96	10.58	8.25	37.10	38.84	41.66
PT (Bus)	13.47	5.74	3.89	6.59	4.42	7.81	27.26	18.59	38.27
PT (Train)	20.57	9.71	13.77	31.03	10.60	9.04	45.58	32.70	38.59
Netherlands									
Car	10.51	8.58	9.99	7.27	6.59	7.03	36.43	23.30	33.56
Train	10.58	7.06	10.84	6.52	6.07	7.55	22.40	19.16	31.85
Bus/Tram	9.85	4.59	8.58	6.22	3.70	6.50	17.16	12.28	30.55

Table 6.2 European-Wide Meta-Analysis of VOT (Part of the Result)

The estimated coefficients on VOT measures of car and PT is similar. According to Trommer et al. (2016), German consumers are often faced with several options when choosing a transport mode, with a dense public transport system and high-quality cycling infrastructure. Thus, the costs of using a car are competing with the costs of PT. However, it should be noticed that the VOT calculation was made based on the total travel time, including in-vehicle travel time, waiting time and/or walking time. The result may be biased due to the respondents' misinterpretations regarding the total travel time and the probable underevaluation of waiting time and/or walking time, as previously stated.

Regarding the VOT measures on AVs, current existing literature presents various results. When compared to the findings of Krueger et al. (2016) and Prateek Bansal et al. (2016), the VOT measures on AT in Munich shows that German consumers are willing to pay more for using fully automated vehicles (Tame, 2008). Nonetheless, all results show the same tendency that VOT for travelling by AVs (both Driverless Taxis and SAVs) is higher than for travelling by private car and PT. Moreover, although no existing study is available to evaluate the VOT measure on AFT, it shows an expected trend that people with a higher VOT having a higher willingness to pay for travel time savings and therefore using AFT.

Safety

The coefficients of *riskier-than-driving level* show to be significant regarding both AT and AFT. The negative sign indicates that using both autonomous transportation modes are expected to be at least as safe as driving a car, in terms of the fatality risk. Meanwhile, it seems that there is a higher expectation for AT to reach the safety level of at least twice safer than driving. However, the result that *safer-than-driving* is not significant for AFT may be questionable due to the potential hypothetical bias. The feedbacks given by the respondents show that respondents may fill out the survey questions with pre-formed opinions regarding safety. Four examples (3 to 6) of the respondents' comments are listed as follows:

3. *„Nebenbeschäftigung und Sicherheitszustand für mich uninteressant."*
   [Translation: I'm not interested in multi-tasking and safety status.]
4. *„Für mich ist der Zeit / Preis Faktor wichtiger als der Sicherheitsaspekt."*
   [Translation: For me the time/price factor is more important than the safety aspect.]

The above three feedbacks indicate that these respondents only paid attention to time and cost attributes.

5. *„Bei der Auswahl des Verkehrsmittels habe ich nur auf Preis & Zeit geachtet. Sicherheit war für mich nicht aussschlaggebend, da ich davon ausgegangen bin, dass angebotene autonome (Luft)taxis sowieso Sicherheitsgeprüft* [*sic*] *wären bevor sie zugelassen werden."*
   [Translation: When choosing the means of transportation, I only paid attention to price & time. Safety was not crucial for me, since I assumed that offered autonomous (air) taxis would be safety tested anyway before they are admitted.]
6. *„Flugtaxis können niemals sicherer sein als bodengebundene Fahrzeuge wegen der zusätzlichen dritten Dimension und der Abhängigkeit vom Wetter."*
   [Translation: Taxis can never be safer than ground-based vehicles because of the additional third dimension and the dependence on the weather.]

In this case, the respondent already pre-formed the opinions towards AFT which may not reflect the real choice behaviour and also lead to a possibly distorted result.

Therefore, it may not be possible to either to reject or to retain *Hypothesis.7* (Individuals will adopt the UAM services when AFT can be at least two times safer than driving. See Table 5.2) until respondents' real choice behaviour being fully understood.

6.2 Discussion of Policy Implication

This section concludes and discusses the findings on transportation modes preferences of different demographic groups, deriving several policy implications regarding individuals' socio-economic status, modality characteristics and trip purposes.

Age, Income and Employment Status

The significant estimation results indicate a possible connection between individuals aged 18 to 35 years old and having 500 € to 3000 € monthly household income and their propensity to use AFT. Within this subgroup, the younger respondents aged 18 to 25 years old are more likely than respondents aged 26 to 35 years old to find AFT more attractive. In contrast, a result based on the main MNL model suggests that individuals aged between 46 and 65 years old are relatively less likely to choose any of the autonomous modes, perhaps because they tend to be less open to trying new technologies (Haboucha et al., 2017). Nevertheless, under the *high-income* group, a strong relationship between *employed* individuals aged 56 to 65 years old and their propensity to use autonomous transportation services is suggested by the result. The result is also in accordance with the attitudes towards willingness to pay for new technological products and environmental-friendly products, expressed by the *high-income* respondents (see Section 4.2).

Based on the outcome mentioned above, it is suggested that *Hypothesis 8* (Younger-aged individuals are relatively more likely to adopt UAM services. See Table 5.2) and *Hypothesis 9* (Individuals with high income are relatively more likely to adopt UAM services. See Table 5.3) might be retained. However, the results also suggested that the motives of using UAM may vary considerably across cohort subgroups (Krueger et al., 2016).

Gender

No significant result was attained from the model estimation based on the completed data set regarding how gender may affect the mode choice. However, based on the reduced dataset concerning respondents with relatively lower income, the estimation result indicates that males having 500 € to 3000 € monthly household income tend to favour PT, AT and AFT more than private car. Regarding the adoption of AFT, no difference can be observed between males and females, which suggests rejecting *Hypothesis 10* (Males are relatively more likely to adopt UAM services. See Table 5.4) regarding the individual profiles with the income level between 500 € to 3000 €.

Education Level

The significant result based on *lower-income profile* MNL shows that individuals with the education level *lower than Bachelor degree* are less likely than more educated individuals to adopt AFT. This finding is also corresponding with the less environmental concern and the relatively more negative attitudes towards the autonomous transportation modes stated by the respondents holding a degree lower than Bachelor (see Section 4.2). This outcome suggests that *Hypothesis 11* (Individuals with lower education levels are relatively less likely to adopt UAM services. See Table 5.4) might be retained, but only regarding the individual profiles with lower income.

Moreover, since no significant result was obtained about the opinion of this group of users regarding AT, the impact of education level on the adoption of autonomous transportation services cannot be directly determined.

Presence of Children (0 to 17 years old) in the Household

The statistically significant relationship is only revealed for respondents with children (between 0 and 17 years old) living in the household and belonging to the high-income group, who are relatively less likely to use AFT than respondents without children living in the households.

It is suggested that *Hypothesis 12* (Individuals with children (0 to 17 years old) living in the households are relatively more likely to adopt UAM services. See Table 5.2) might be rejected, but only based on the high-income profile MNL model result. The heterogeneity among cohort subgroups should also be emphasised here.

Car Availability

The significant results suggest that respondents with no car available in the household find the PT the most attractive transport mode in Munich, but they tend to prefer autonomous modes over the private car. Especially the individuals belonging to the *high-income* group are likely to have a relatively higher propensity to use AT. However, compared with individuals with car available in the households, individuals with no car available are likely to have lower propensity to use both autonomous modes.

This outcome suggests that *Hypothesis 13* (Individuals with car available in the households are relatively more likely to adopt UAM services. See Table 5.2) might be retained based on the main MNL model result.

Current Means of Transport

The results suggest that the current PT and soft mode users are relatively less likely to switch to the option AT or AFT from PT. Perhaps because current PT users are somewhat satisfied with the public transport systems in Munich (MVG Ganz einfach mobil, n.d.), and therefore, the PT users involved indicated above-average satisfaction regarding their current travel pattern (see Section 4.2). Also, the shared autonomous modes are found to be preferred over the private car for PT users, perhaps because these users are less hesitant to use shared mobility options (Krueger et al., 2016). Moreover, the PT users having relatively lower income may have the similar attitudes towards the private car and AT, but switching to AFT seems relatively unlikely. Regarding the soft mode users having relatively lower income, AFT is likely to be the least attractive transport alternative, and these users may either find none of the available choices is desirable to use or expect other alternatives to be provided, such as bike and walking (as they stated in the survey comment). This can possibly be explained by the fact that a large part of Munich's cyclists is satisfied with the existing bicycle traffic system (Landeshauptstadt München, 2010) and the relatively high level of satisfaction expressed by the respondents who are the current soft mode users (see Section 4.2).

Moreover, comparing with the respondents who currently travel by car as driver most frequently, respondents travelled by PT or soft modes most frequently are less likely to use both services provided by autonomous modes. This outcome suggests that *Hypothesis 14* (Individuals who travel by car as driver most frequently are relatively more likely to adopt UAM services. See Table 5.2) might be retained based on the main MNL model result.

Trip Purpose

The significant results suggest that for the commuting trip purpose, PT is considered as the most desirable transport alternative, followed by the private car and AT, while AFT seems relatively least likely to be selected. Individuals may be relatively less open to use novel mobility options (Krueger et al., 2016), comparing to the choice regarding non-commuting private trips. The is also complementary to the survey result concerning the likelihood to use AFT for different trip purposes (see Section 4.2).

This outcome suggests that *Hypothesis 15* (UAM services are relatively less likely to be used for daily commutes. See Table 5.2) might be retained based on the main MNL model result.

Hypothesis	Retain	Reject	Neither retain or reject
1	✓		
2	✓		
3			O
4	✓		
5	✓		
6			O
7			O
8	✓ (general)		
9	✓ (general)		
10		✗ (one group)	
11	✓ (one group)		
12		✗ (one group)	
13	✓ (general)		
14	✓ (general)		
15	✓ (general)		

Table 6.3 Summary of Hypotheses Tests Results

7 General Discussion and Conclusion

This chapter discusses about the aspects that this research could not cover due to the limitations of time and analysis effort. Recommendations and directions of future work are also proposed regarding further development. A general conclusion regarding the whole research project is given in the end.

7.1 Limitations and Recommendations

This section identifies the current limitations concerning the experimental design, possible sample bias, and several simplifications that have been made for conducting this research.

SC Experiment Design

One of the limitations concerns about the choice experiment setting. In order to specify the choice scenarios, a hypothetical 15 km travel distance was given in front of the choice tasks, the attributes total travel time and travel cost were thus defined correspondingly. In the previous studies concerning the preference of AVs or SAVs, it was common that the respondent-specific reference alternative was included in the choice scenarios, meaning that respondents were required to fill in some information about respondents' current travel patterns, such as travel distance and travel mode, the hypothetical alternatives were then generated and shown accordingly. However, in this case, when the alternative AFT with the certain operation range is included, the reference trip distance is expected to be above certain threshold. To achieve that, only respondents who report rather long distance (e.g. at least 15 km per direction) for both commuting and non-commuting purposes should be included, which would probably require more survey effort to be invested. However, it would also be problematic to entirely exclude the shorter-distance traveller, as their travel distance may increase due to the occurrence of the new flying mode in the future. The Zip-code information may be valid for understanding the current commuting distance based on respondents' geographical locations. However, due to the analysis complexity, it was not considered in this research. Further researches may consider the aspects and issues mentioned above.

Another major limitation is the hypothesis bias due to the hypothetical nature of the SC experiment. Firstly, the respondents may have predispositions regarding provided autonomous transportation modes, and thus understand the choice scenarios differently. Further attempts could ensure that all respondents can envision the same vehicle concept and fully understand the choice task settings. Secondly, the preferences stated by the respondents of the survey may not accurately reflect consumers' preference by the time the hypothetical alternatives are available in the market (Krueger et al., 2016). This may be overcome by implementing longitudinal studies to investigate the choice decisions at different points in time (Haboucha et al., 2017).

Possible Sample Bias

It is possible that individuals with pre-formed attitudes towards autonomous transportation modes are more likely to respond (Haboucha et al., 2017). Further research is expected to pay more attention to controlling individual characteristics to reduce the potential sample bias.

Simplifications

Several simplifications have been made regarding the data analysis. Firstly, during the modelling process, two datasets based on two trip purposes were merged, while trip purposes have been set as one of the choice attributes. In order to make the result more accurate, separate models could be established to make a further examination. Furthermore, the missing income values were coded as another category and were excluded from model estimations. It would be ideal to handle the missing data based on valid imputation methods and thus include them in the models.

7.2 Further Development

This section presents some recommendations that could be considered as further steps for improving this thesis.

Modelling Methodology

Modelling and analysing choice behaviours considering the embracement of novel transportation modes is a complex process. Due to the restriction of time, the interpretation of the results was based on only the MNL models. Nevertheless, the MNL model should always be the starting point for establishing more advanced models (Hensher et al., 2015, p.611). Several aspects could be considered for further model development are described as follows:

1. As some unexpected errors occurred when implementing the NL models with one-level nested structure (including *none* alternative as a nest), some further attempts could be made regarding improving the nested structures, for example, using a multi-level choice of nest instead of single-level nested structure.

2. ML models can be further developed based on the full sample to reveal the source of taste heterogeneity. The estimation of MNL model may be of limited value in the a priori selection of random parameterised attributes unless extensive segmentation on each attribute occurs (Hensher et al., 2015, p. 611). McFadden & Train (2000) proposed the Lagrange Multiplier tests which may assist in the establishment of candidate random parameter. More details see Hensher et al. (2015).

Further Analysis Regarding the Transportation Modes Preferences

Several further steps could be taken regarding exploring the modes preferences:

1. The appropriateness of various policies can be evaluated with the measures of responsiveness of market shares to changes in certain attributes (Louviere et al., 2000), such as travel time, travel cost, and safety level.

2. The scope of the choice experiment could be expanded by including more trip purposes, differing trip distances/durations, and various transportation mode alternatives.

3. Latent attitudes that were found to be influential to the choice behaviour was analysed with demographical attributes preliminarily. Further efforts could be made to see how they are related to the choice behaviour by establishing, for example, the hybrid choice models with latent variables.

7.3 Conclusion

The convergence of technologies and new business models enabled by the digital revolution is nowadays making it possible to explore UAM as a new way for people to move within the cities. Taking Munich, Germany as a case study, this thesis presents the development of a transportation mode choice model for exploring the preferences for transportation modes in a hypothetical UAM environment.

Two main objectives are defined. One is to estimate the potential influence of the service attributes which may affect the choice among given transport alternatives, notably, the adoption of AFT and UAM. The other one is to identify the characteristics of the potential user groups who are likely to adopt the autonomous transportation services, especially the services of AFT and UAM. In working towards the objectives, an SP survey was conducted from mid-February 2018 to April 2018, and 248 valid responses were collected. Flyers containing survey information were distributed online and en-route to recruit respondents. After examining several discrete choice model structures developed, a main MNL model together with two profile MNL models was decided to used for the interpretation of the statistical results.

The interpreted results indicate that the survey respondents may be willing to pay more for using autonomous transportation modes. An expected trend has been revealed that the respondents with a higher VOT may be willing to pay more for travel time savings and therefore using AFT and UAM services. Meanwhile, regardless of respondents' preassumption concerning safety performance, safety may be a critical determinant of adoption of both autonomous transportation services. Moreover, some policy implications were derived. The results based on this case study suggest that market penetration rates for AFT and UAM may be greater among respondents with following characteristics:

- younger-aged respondents (between 18 and 35 years old),
- older-aged (between 56 to 65 years old) respondents with high income who also have a relatively high propensity to use an AT,
- respondents with children (0 to 17 years old) living in the household (although this is not consistent with the characteristics of the *high-income profile*)

However, switching to any of the autonomous transportation alternatives is not relatively more likely if the respondents currently use PT or soft modes most frequently. Last but not least, during the market entry stage, AFT and UAM may be more desirable for performing other trip purposes such as business trips instead of daily commutes.

The research can be further developed from the SP design and modelling methodologies perspectives. Existing taste heterogeneity in the cohort subgroups is expected to be further examined and handled. Nonetheless, despite a potential hypothetical bias, the results provide a preliminary understanding of the transportation modes preferences in a hypothetical UAM environment and the relative importance of the attributes of interest.

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Appendix A: Individual Background Attributes and Levels

Background attribute	Levels	Source
Age	18-25	
	26-35	
	36-45	
	46-55	
	56-65	
	> 65	
Gender	Male	
	Female	
Presence of children (0-17 years old) in the household[19]	Yes	
	No	
Employment status	Employed (full time & part time)	
	Student	
	Others	
Education level	Lower than Bachelor's degree	
	Bachelor's degree	
	Master's degree	
	PhD	
Household monthly income	<500€	
	500€-1000€	
	1000€-2000€	
	2000€-3000€	
	3000€-4000€	
	4000€-5000€	
	5000€-6000€	
	6000€-7000€	
	>7000€	
Current means of transportation	Car as driver	
	PT	
	Soft modes including cycling and walking	
Car availability[20]	Yes	
	No	
Trip Purpose	Commuting trip	
	Non-commuting trip	
Environmental concern	I am concerned about global warming.	Atasoy et al. (2013)
	I do not change my behaviour based on environmental concerns.	Adapted from Ewing & Sarigöllü (2000)
	It is acceptable for an industrial society such as ours to cause some pollution.	Ewing & Sarigöllü (2000)
	I am willing to spend a bit more to buy a product that is more environmentally friendly.	Ewing & Sarigöllü (2000)& Kim, Chung, & Kim (2013)

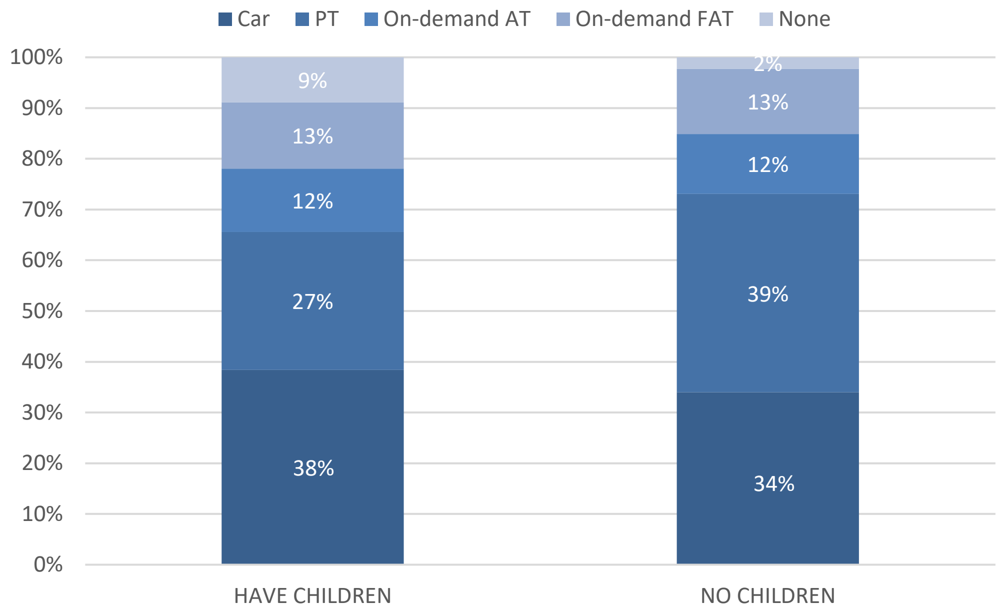
[19] Number of children has been regrouped into two groups according to the presence of children.

[20] Number of car in the household has been regrouped into two groups according to the car availability.

Appendix A (continued)

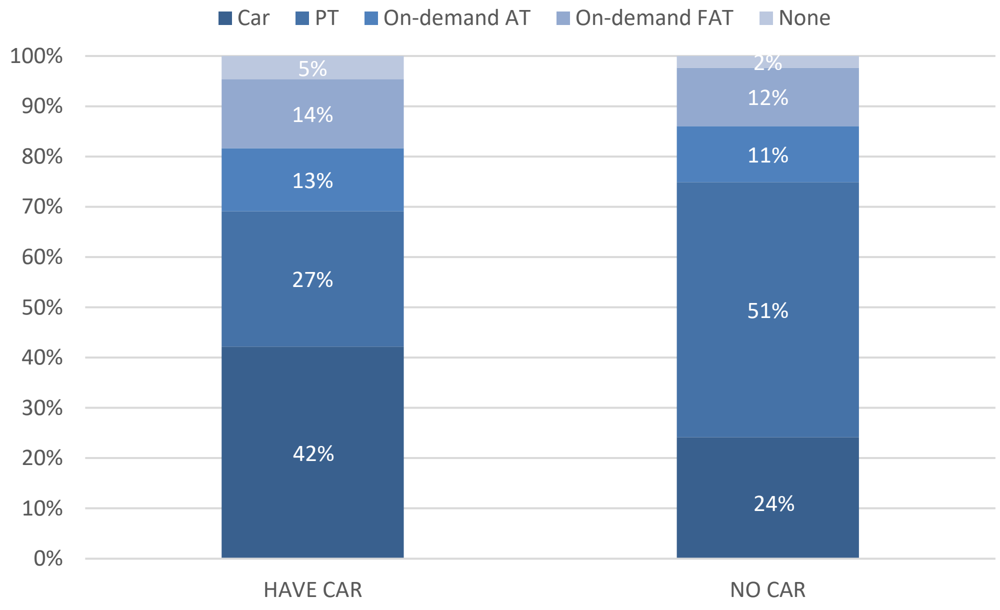
Background attribute	Levels	Source
Technological concern	I am excited by the possibilities offered by new technologies to me.	Ewing & Sarigöllü (2000)
	I often use new technological products, even though they are expensive.	Jensen, Cherchi, & Ortúzar (2014)
	I have little to no interest in new technology.	Adapted from Roehrich, (2004)
	New technology causes more problems than it solves.	Ewing & Sarigöllü (2000)
Attitudes towards autonomous technology	I would find it fun to use autonomous transport modes.	Created for this study
	I have a fear of using self-driving taxi.	Created for this study
	Autonoumous transport modes should play an important role in our mobility system.	Adapted from Jensen et al.
	I have a fear of taking autonomous flying taxi.	Created for this study

Appendix B: The Impacts of Demographic Variables on Choice Decisions



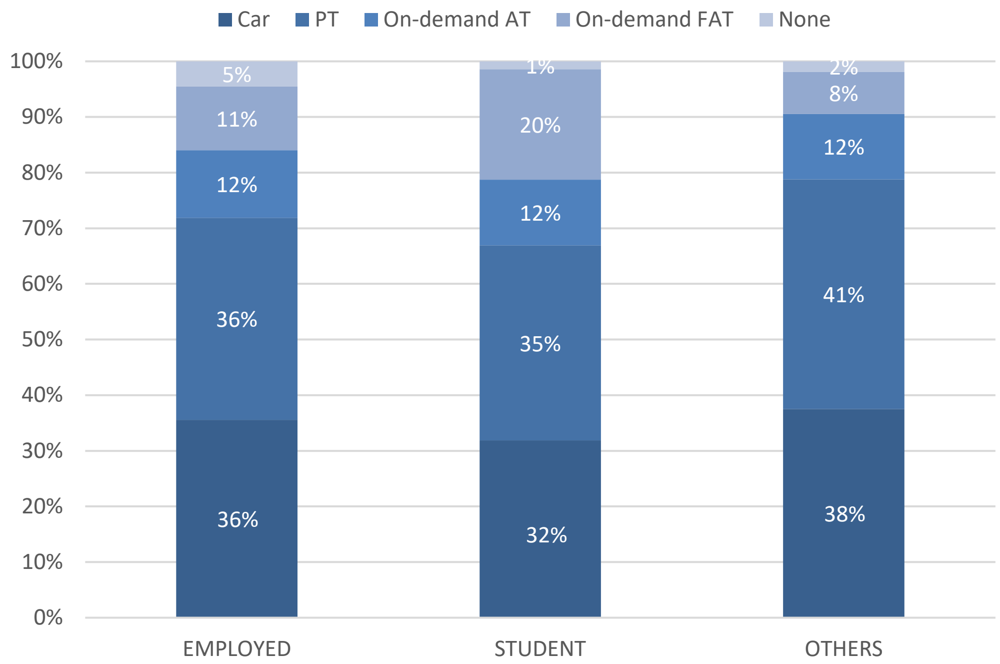
*p < 0.01 regarding within Attribute Chi-Square; P < 0.05 regarding between group Chi-Square

Appendix B-1. Mode Choice Decision Influenced by Presence of Children in the Household



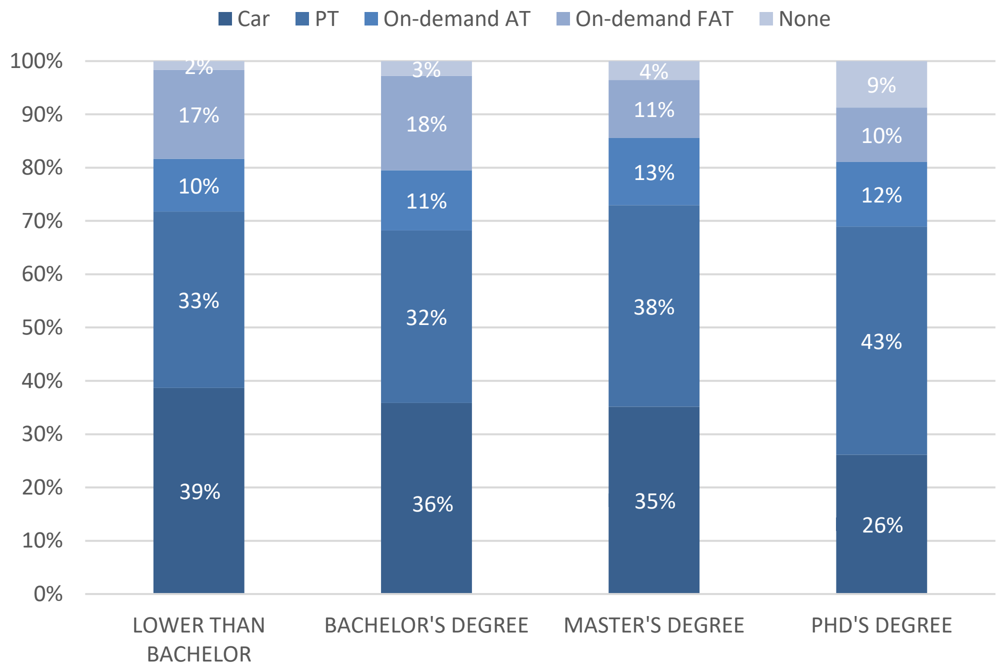
*p < 0.01 regarding within Attribute Chi-Square and between group Chi-Square

Appendix B-2. Mode Choice Decision Influenced by Car Availability



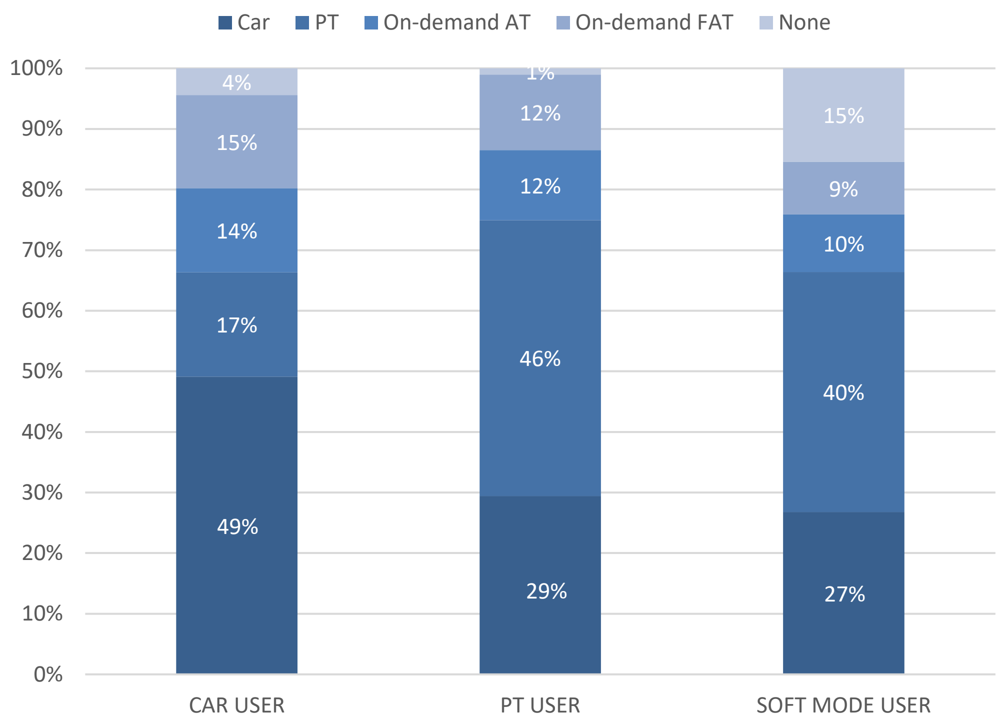
*p < 0.01 regarding within Attribute Chi-Square and between group Chi-Square

Appendix B-3. Mode Choice Decision Influenced by Employment Status



*p < 0.01 regarding within Attribute Chi-Square; P < 0.05 regarding between group Chi-Square

Appendix B-4. Mode Choice Decision Influenced by Education Level



*p < 0.01 regarding within Attribute Chi-Square and between group Chi-Square

Appendix B-5. Mode Choice Decision Influenced by Current Means of Transportation

Appendix C: Specifications of the Utility Functions

Variable	Description
CAR_TT	Car total travel time [minutes]
CAR_CO	Car total travel cost [Euros]
CAR_INC	Car walking time [minutes]
PT_TT	PT total travel time [minutes]
PT_CO	PT total travel cost [Euros]
PT_INC	PT walking time and waiting time [minutes]
AT_TT	AT total travel time [minutes]
AT_CO	AT total travel cost [Euros]
AT_INC	AT waiting time [minutes]
AFT_TT	AFT total travel time [minutes]
AFT_CO	AFT total travel cost [Euros]
AFT_INC	AFT walking time and waiting time [minutes]
AT_SF_safer	AT at least two times safer than driving
AT_SF_ds	AT driving level safety
AT_SF_riskier	AT two times riskier than driving
AFT_SF_safer	AFT at least two times safer than driving
AFT_SF_ds	AFT driving level safety
AFT_SF_riskier	AFT two times riskier than driving
MALE	Male
FEMALE	Female
AGE1	Age 18-25
AGE2	Age 26-35
AGE3	Age 36-45
AGE4	Age 46-55
AGE5	Age 56-65
AGE6	Age older than 65
LOWERTHANBSC	Education lower than bachelor
BSC	Education Bachelor
MSC	Education Master
PHD	Education PhD
CHILDREN	Have children (0-17 years old) in the household
NOCHILDREN	No children (0-17 years old) in the household
CARUSER	Respondents using car(driver) most frequently
PTUSER	Respondents using PT most frequently
SMUSER	Respondents using soft modes most frequently
HAVECAR	Have car available in the household
NOCAR	No car available in the household
WORKING	Respondents who are employed
STUDENT	Respondents who are student
OTHERS	Respondents with other employment status
COM	Commuting trip
NONCOM	Non-commuting private trip
INCOME1	Household monthly income less than 500 Euros
INCOME2	Household monthly income between 500 and 1000 Euros
INCOME3	Household monthly income between 1000 and 2000 Euros
INCOME4	Household monthly income between 2000 and 3000 Euros
INCOME5	Household monthly income between 3000 and 4000 Euros
INCOME6	Household monthly income between 4000 and 5000 Euros
INCOME7	Household monthly income between 5000 and 6000 Euros
INCOME8	Household monthly income between 6000 and 7000 Euros
INCOME9	Household monthly income more than 7000 Euros

Appendix C-1. Description of Variables Included in the Utility Functions

Appendix C-2. Specifications of the Utility Functions of MNL Model Including *none* Alternative

V(CAR) = B_CAR_TIME [21] * CAR_TT_SCALED + B_CAR_COST * CAR_COST_SCALED + B_MALE_CAR * MALE + B_FEMALE_CAR * FEMALE + B_AGE3_CAR * AGE3 + B_AGE5_CAR * AGE5 + B_AGE6_CAR * AGE6 + B_BSC_CAR * BSC + B_CARUSER_CAR * CARUSER + B_NONCARUSER_CAR * PTUSER + B_NONCARUSER_CAR * SMUSER + B_HAVECAR_CAR * HAVECAR + B_NOCAR_CAR * NOCAR + B_WORKING_CAR * WORKING + B_STUDENT_CAR * STUDENT + B_OTHERS_CAR * OTHERS + B_COM_CAR * COM + B_NONCOM_CAR * NONCOM + B_INCOME1_CAR * INCOME1 + B_INCOME5_CAR * INCOME5 + B_INCOME9_CAR * INCOME9

V(PT) = ASC_PT + B_PT_TIME * PT_TT_SCALED + B_PT_COST * PT_COST_SCALED + B_PT_INC * PT_INC_SCALED + B_MALE_PT * MALE + B_FEMALE_PT * FEMALE + B_AGE1_PT * AGE1 + B_AGE2_PT * AGE2 + B_AGE3_PT * AGE3 + B_AGE4_PT * AGE4 + B_AGE5_PT * AGE5 + B_AGE6_PT * AGE6 + B_LOWERTHANBSC_PT * LOWERTHANBSC + B_BSC_PT * BSC + B_MSC_PT * MSC + B_PHD_PT * PHD + B_CARUSER_PT * CARUSER + B_PTUSER_PT * PTUSER + B_SMUSER_SM * SMUSER + B_HAVECAR_PT * HAVECAR + B_NOCAR_PT * NOCAR + B_WORKING_PT * WORKING + B_STUDENT_PT * STUDENT + B_OTHERS_PT * OTHERS + B_COM_PT * COM + B_NONCOM_PT * NONCOM + B_INCOME1_PT * INCOME1 + B_INCOME2_PT * INCOME2 + B_INCOME3_PT * INCOME3 + B_INCOME4_PT * INCOME4 + B_INCOME5_PT * INCOME5 + B_INCOME6_PT * INCOME6 + B_INCOME7_PT * INCOME7 + B_INCOME8_PT * INCOME8 + B_INCOME9_PT * INCOME9

V(AT) = ASC_AT + B_AT_TIME * AT_TT_SCALED + B_AT_COST * AT_COST_SCALED + B_safer_AT * AT_SAFETY_safer + B_riskier_AT * AT_SAFETY_riskier + B_AGE3_AT * AGE3 + B_OLDER_AUTO * AGE4 + B_OLDER_AUTO * AGE5 + B_BSC_AT * BSC + B_CARUSER_AT * CARUSER + B_PTUSER_AUTO * PTUSER + B_SMUSER_AT * SMUSER + B_HAVECAR_AT * HAVECAR + B_NOCAR_AUTO * NOCAR + B_WORKING_AT * WORKING + B_COM_AT * COM + B_NONCOM_AT * NONCOM + B_INCOME2_AT * INCOME2 + B_INCOME5_AT * INCOME5 + B_INCOME9_AT * INCOME9

V(AFT) = ASC_AFT + B_AFT_TIME * AFT_TT_SCALED + B_AFT_COST * AFT_COST_SCALED + B_riskier_AFT * AFT_SAFETY_riskier + B_AGE3_AFT * AGE3 + B_OLDER_AUTO * AGE4 + B_OLDER_AUTO * AGE5 + B_AGE6_AFT * AGE6 + B_BSC_AFT * BSC + B_CHILDREN_AFT * CHILDREN + B_NOCHILDREN_AFT * NOCHILDREN + B_CARUSER_AFT * CARUSER + B_PTUSER_AUTO * PTUSER + B_SMUSER_AFT * SMUSER + B_HAVECAR_AFT * HAVECAR + B_NOCAR_AUTO * NOCAR + B_WORKING_AFT * WORKING + B_STUDENT_AFT * STUDENT+ B_COM_AFT * COM + B_NONCOM_AFT * NONCOM + B_INCOME2_AFT * INCOME2 + B_INCOME3_AFT * INCOME3 + B_INCOME4_AFT * INCOME4 + B_INCOME5_AFT * INCOME5 + B_INCOME8_AFT * INCOME8 + B_INCOME9_AFT * INCOME9

V(NONE) = B_NONE * NONE + B_AGE6_NONE * AGE6 + B_BSC_NONE * BSC + B_CHILDREN_NONE * CHILDREN + B_NOCHILDREN_NONE * NOCHILDREN + B_CARUSER_NONE * CARUSER + B_PTUSER_NONE * PTUSER + B_HAVECAR_NONE * HAVECAR + B_WORKING_NONE * WORKING + B_INCOME1_NONE * INCOME1 + B_INCOME4_NONE * INCOME4 + B_INCOME5_NONE * INCOME5 + B_INCOME8_NONE * INCOME8 + B_INCOME9_NONE * INCOME9

[21] B represents β.

Appendix C-3. Specifications of the Utility Functions of MNL Model Excluding *none* Alternative

V(CAR) = B_CAR_TIME * CAR_TT_SCALED + B_CAR_COST * CAR_COST_SCALED + B_AGE3_CAR * AGE3 + B_AGE5_CAR * AGE5 + B_AGE6_MODES * AGE6 + B_BSC_CAR * BSC + B_CARUSER_CAR * CARUSER + B_PTUSER_CAR * PTUSER + B_SMUSER_CAR * SMUSER + B_HAVECAR_CAR * HAVECAR + B_NOCAR_CAR * NOCAR + B_WORKING_CAR * WORKING + B_STUDENT_CAR * STUDENT + B_OTHERS_CAR * OTHERS + B_COM_CAR * COM + B_NONCOM_CAR * NONCOM + B_INCOME1_CAR * INCOME1 + B_INCOME5_CAR * INCOME5 + B_INCOME9_CAR * INCOME9

V(PT) = ASC_PT + B_PT_TIME * PT_TT_SCALED + B_PT_COST * PT_COST_SCALED + B_PT_INC * PT_INC_SCALED + B_MALE_PT * MALE + B_FEMALE_PT * FEMALE + B_AGE1_PT * AGE1 + B_AGE2_PT * AGE2 + B_AGE3_PT * AGE3 + B_AGE4_PT * AGE4 + B_AGE5_PT * AGE5 + B_AGE6_PT * AGE6 + B_LOWERTHANBSC_PT * LOWERTHANBSC + B_BSC_PT * BSC + B_MSC_PT * MSC + B_PHD_PT * PHD + B_CARUSER_PT * CARUSER + B_PTUSER_PT * PTUSER + B_SMUSER_SM * SMUSER + B_HAVECAR_PT * HAVECAR + B_NOCAR_PT * NOCAR + B_WORKING_PT * WORKING + B_STUDENT_PT * STUDENT + B_OTHERS_PT * OTHERS + B_COM_PT * COM + B_NONCOM_PT * NONCOM + B_INCOME1_PT * INCOME1 + B_INCOME2_PT * INCOME2 + B_INCOME3_PT * INCOME3 + B_INCOME4_PT * INCOME4 + B_INCOME5_PT * INCOME5 + B_INCOME6_PT * INCOME6 + B_INCOME7_PT * INCOME7 + B_INCOME8_PT * INCOME8 + B_INCOME9_PT * INCOME9

V(AT) = ASC_AT + B_AT_TIME * AT_TT_SCALED + B_AT_COST * AT_COST_SCALED + B_safer_AT * AT_SAFETY_safer + B_riskier_AT * AT_SAFETY_riskier + B_AGE3_AT * AGE3 + B_OLDER_AUTO * AGE4 + B_OLDER_AUTO * AGE5 + B_BSC_AT * BSC + B_CARUSER_AT * CARUSER + B_PTUSER_AUTO * PTUSER + B_SMUSER_AT * SMUSER + B_HAVECAR_AT * HAVECAR + B_NOCAR_AT * NOCAR + B_WORKING_AT * WORKING + B_COM_AT * COM + B_NONCOM_AT * NONCOM + B_INCOME2_AT * INCOME2 + B_INCOME5_AT * INCOME5 + B_INCOME9_AT * INCOME9

V(AFT) = ASC_AFT + B_AFT_TIME * AFT_TT_SCALED + B_AFT_COST * AFT_COST_SCALED + B_riskier_AFT * AFT_SAFETY_riskier + B_AGE3_AFT * AGE3 + B_OLDER_AUTO * AGE4 + B_OLDER_AUTO * AGE5 + B_AGE6_MODES * AGE6 + B_BSC_AFT * BSC + B_CARUSER_AFT * CARUSER + B_PTUSER_AUTO * PTUSER + B_SMUSER_AFT * SMUSER + B_HAVECAR_AFT * HAVECAR + B_NOCAR_AFT * NOCAR + B_WORKING_AFT * WORKING + B_STUDENT_AFT * STUDENT + B_COM_AFT * COM + B_NONCOM_AFT * NONCOM + B_INCOME2_AFT * INCOME2 + B_INCOME3_AFT * INCOME3 + B_INCOME4_AFT * INCOME4 + B_INCOME5_AFT * INCOME5 + B_INCOME8_AFT * INCOME8 + B_INCOME9_AFT * INCOME9 + B_NOCHILDREN_AFT * NOCHILDREN

Appendix C-4. Specifications of the Utility Functions of *High-income*-based MNL Model Excluding *none* Alternative

V(CAR) = ASC_CAR + B_CAR_TIME * CAR_TT_SCALED + B_CAR_COST * CAR_COST_SCALED + B_AGE3_CAR * AGE3 + B_AGE4_CAR * AGE4 + B_AGE5_CAR * AGE5 + B_CARUSER_CAR * CARUSER + B_PTUSER_CAR * PTUSER + B_SMUSER_CAR * SMUSER + B_INCOME9_COM * INCOME9 * COM

V(PT) = B_PT_TIME * PT_TT_SCALED + B_AGE1_PT * AGE1 + B_AGE2_PT * AGE2 + B_AGE3_PT * AGE3 + B_AGE4_PT * AGE4 + B_AGE5_PT * AGE5 + B_AGE6_PT * AGE6 + B_CARUSER_PT * CARUSER + B_PTUSER_PT * PTUSER + B_SMUSER_PT * SMUSER + B_HAVECAR_PT * HAVECAR + B_NOCAR_PT * NOCAR + B_INCOME9_COM * INCOME9 * COM

V(AT) = ASC_AT + B_AT_TIME * AT_TT_SCALED + B_AGE3_AT * AGE3 + B_AGE5_AUTO * AGE5 + B_CARUSER_AT * CARUSER + B_PTUSER_AUTO * PTUSER + B_HAVECAR_AT * HAVECAR + B_NOCAR_AT * NOCAR + B_INCOME9_COM * INCOME9 * COM

V(AFT) = B_AFT_COST * AFT_COST_SCALED + B_AGE3_AFT * AGE3 + B_AGE5_AUTO * AGE5 + B_CHILDREN_AFT * CHILDREN + B_NOCHILDREN_AFT * NOCHILDREN + B_CARUSER_AFT * CARUSER + B_PTUSER_AUTO * PTUSER + B_INCOME9_COM * INCOME9 * COM

Appendix C-5. Specifications of the Utility Functions of *High-income*-based MNL Model Including *none* Alternative

V(CAR) = B_CAR_TIME * CAR_TT_SCALED + B_MALE_CAR * MALE + B_FEMALE_CAR * FEMALE + B_AGE3_CAR * AGE3 + B_AGE4_CAR * AGE4 + B_LOWERTHANBSC_CAR * LOWERTHANBSC + B_BSC_CAR * BSC + B_MSC_CAR * MSC + B_PHD_CAR * PHD + B_CHILDREN_CAR * CHILDREN + B_NOCHILDREN_CAR * NOCHILDREN + B_CARUSER_CAR * CARUSER + B_PTUSER_CAR * PTUSER + B_WORKING_CAR * WORKING

V(PT) = ASC_PT + B_MALE_PT * MALE + B_FEMALE_PT * FEMALE + B_AGE2_PT * AGE2 + B_AGE3_PT * AGE3 + B_AGE4_PT * AGE4 + B_AGE5_PT * AGE5 + B_LOWERTHANBSC_PT * LOWERTHANBSC + B_BSC_PT * BSC + B_MSC_PT * MSC + B_PHD_PT * PHD + B_CHILDREN_PT * CHILDREN + B_NOCHILDREN_PT * NOCHILDREN + B_CARUSER_PT * CARUSER + B_PTUSER_PT * PTUSER + B_SMUSER_PT * SMUSER + B_HAVECAR_PT * HAVECAR + B_NOCAR_PT * NOCAR + B_WORKING_PT * WORKING + B_INCOME9_COM_PT * INCOME9 * COM

V(AT) = B_AT_TIME * AT_TT_SCALED + B_safer_AT * AT_SAFETY_safer + B_MALE_AT * MALE + B_FEMALE_AT * FEMALE + B_AGE3_AT * AGE3 + B_BSC_AT * BSC + B_MSC_AT * MSC + B_CARUSER_AT * CARUSER + B_PTUSER_AT * PTUSER + B_HAVECAR_AT * HAVECAR + B_NOCAR_AT * NOCAR + B_WORKING_AT * WORKING

V(AFT) = B_AFT_COST * AFT_COST_SCALED + B_AGE3_AFT * AGE3 + B_AGE4_AFT * AGE4 + B_AGE5_AFT * AGE5 + B_BSC_AFT * BSC + B_CARUSER_AFT * CARUSER + B_WORKING_AFT * WORKING

V(NONE) = B_AGE3_NONE * AGE3 + B_BSC_NONE * BSC + B_CHILDREN_NONE * CHILDREN + B_NOCHILDREN_NONE * NOCHILDREN + B_CARUSER_NONE * CARUSER + B_SMUSER_NONE * SMUSER + B_WORKING_NONE * WORKING

Appendix C-6. Specifications of the Utility Functions of *High-income*-based ML Model Including *none* Alternative

V(CAR) = ASC_RND[22] + B_CAR_TIME * CAR_TT_SCALED + B_CAR_COST * CAR_COST_SCALED + B_AGE3_CAR * AGE3 + B_AGE4_CAR * AGE4 + B_CHILDREN_CAR * CHILDREN + B_NOCHILDREN_CAR * NOCHILDREN + B_CARUSER_CAR * CARUSER + B_PTUSER_CAR * PTUSER + B_SMUSER_CAR * SMUSER + B_BSC_CAR * BSC

V(PT) = B_AGE2_PT * AGE2 + B_AGE3_PT * AGE3 + B_AGE4_PT * AGE4 + B_AGE5_PT * AGE5 + B_CHILDREN_PT * CHILDREN + B_NOCHILDREN_PT * NOCHILDREN + B_CARUSER_PT * CARUSER + B_PTUSER_PT * PTUSER + B_SMUSER_PT * SMUSER + B_HAVECAR_PT * HAVECAR + B_NOCAR_PT * NOCAR + B_INCOME9_COM_PT * INCOME9 * COM + B_MALE_PT * MALE +

[22] RND represents random parameter.

B_FEMALE_PT * FEMALE + B_LOWERTHANBSC_PT * LOWERTHANBSC + B_BSC_PT * BSC + B_MSC_PT * MSC + B_PHD_PT * PHD

V(AT) = ASC_RND + B_AT_TIME * AT_TT_SCALED + B_safer_AT * AT_SAFETY_safer + B_AGE3_AT * AGE3 + B_NOCHILDREN_AT * NOCHILDREN + B_CARUSER_AT * CARUSER + B_HAVECAR_AT * HAVECAR + B_INCOME9_COM_AUTO * INCOME9 * COM + B_BSC_AT * BSC

V(AFT) = ASC_RND + B_AFT_COST * AFT_COST_SCALED + B_AGE3_AFT * AGE3 + B_CHILDREN_AFT * CHILDREN + B_NOCHILDREN_AFT * NOCHILDREN + B_CARUSER_AFT * CARUSER + B_INCOME9_COM_AUTO * INCOME9 * COM + B_BSC_AFT * BSC + B_PHD_AFT * PHD

V(NONE) = B_AGE3_NONE * AGE3 + B_CARUSER_NONE * CARUSER + B_FEMALE_NONE * FEMALE + B_BSC_NONE * BSC + B_MSC_NONE * MSC + B_PHD_NONE * PHD

Appendix C-7. Specifications of the Utility Functions of *Lower-income*-based MNL Model Including *none* Alternative

V(CAR) = ASC_CAR + B_CAR_TIME * CAR_TT_SCALED + B_CAR_COST * CAR_COST_SCALED + B_MALE_CAR * MALE + B_FEMALE_CAR * FEMALE + B_AGE1_CAR * AGE1 + B_AGE3_CAR * AGE3 + B_AGE4_CAR * AGE4 + B_BSC_CAR * BSC + B_CARUSER_CAR * CARUSER + B_PTUSER_SCAR * PTUSER + B_SMUSER_SCAR * SMUSER+ B_HAVECAR_CAR * HAVECAR + B_NOCAR_CAR * NOCAR + B_COM_CAR * COM + B_NONCOM_CAR * NONCOM

V(PT) = ASC_PT + B_PT_TIME * PT_TT_SCALED + B_PT_COST * PT_COST_SCALED + B_MALE_PT * MALE + B_FEMALE_PT * FEMALE + B_AGE1_PT * AGE1 + B_AGE2_PT * AGE2 + B_AGE3_PT * AGE3 + B_AGE4_PT * AGE4 + B_AGE6_PT * AGE6 + B_LOWERTHANBSC_PT * LOWERTHANBSC + B_BSC_PT * BSC + B_MSC_PT * MSC + B_PHD_PT * PHD + B_CHILDREN_PT * CHILDREN + B_NOCHILDREN_PT * NOCHILDREN + B_CARUSER_PT * CARUSER + B_PTUSER_PT * PTUSER + B_SMUSER_PT * SMUSER + B_HAVECAR_PT * HAVECAR + B_NOCAR_PT * NOCAR + B_COM_PT * COM + B_NONCOM_PT * NONCOM

V(AT) = ASC_AT + B_AT_TIME * AT_TT_SCALED + B_AT_COST * AT_COST_SCALED + B_safer_AT * AT_SAFETY_safer + B_AGE3_AT * AGE3 + B_BSC_AT * BSC + B_CARUSER_AT * CARUSER + B_PTUSER_SCAR * PTUSER + B_SMUSER_SCAR * SMUSER + B_HAVECAR_AT * HAVECAR + B_NOCAR_AT * NOCAR + B_COM_AT * COM + B_NONCOM_AT * NONCOM

V(AFT) = B_AFT_TIME * AFT_TT_SCALED + B_AFT_COST * AFT_COST_SCALED + B_AGE1_AFT * AGE1 + B_AGE2_AFT * AGE2 + B_AGE3_AFT * AGE3 + B_LOWERTHANBSC_AFT * LOWERTHANBSC + B_BSC_AFT * BSC + B_CARUSER_AFT * CARUSER + B_PTUSER_AFT * PTUSER + B_SMUSER_AFT * SMUSER + B_HAVECAR_AFT * HAVECAR + B_NOCAR_AFT * NOCAR + B_COM_AFT * COM + B_NONCOM_AFT * NONCOM

V(NONE) = B_NONE * NONE + B_AGE3_NONE * AGE3 + B_AGE5_NONE * AGE5 + B_BSC_NONE * BSC + B_MSC_NONE * MSC + B_CHILDREN_NONE * CHILDREN + B_NOCHILDREN_NONE * NOCHILDREN + B_CARUSER_NONE * CARUSER + B_PTUSER_NONE * PTUSER + B_SMUSER_NONE * SMUSER + B_HAVECAR_NONE * HAVECAR

Appendix C-8. Specifications of the Utility Functions of *Lower-income*-based MNL Model Excluding *none* Alternative

V(CAR) = ASC_CAR + B_CAR_TIME * CAR_TT_SCALED + B_CAR_COST * CAR_COST_SCALED + B_MALE_CAR * MALE + B_FEMALE_CAR * FEMALE + B_AGE3_CAR * AGE3 + B_AGE4_CAR * AGE4 + B_BSC_CAR * BSC + B_CARUSER_CAR * CARUSER + B_PTUSER_CAR * PTUSER + B_SMUSER_CAR * SMUSER + B_HAVECAR_CAR * HAVECAR + B_NOCAR_CAR * NOCAR + B_WORKING_CAR * WORKING + B_STUDENT_CAR * STUDENT + B_COM_CAR * COM + B_NONCOM_CAR * NONCOM

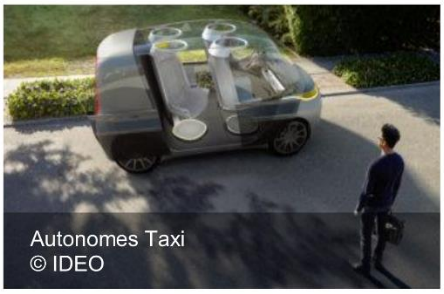
V(PT) = ASC_PT + B_PT_TIME * PT_TT_SCALED + B_MALE_PT * MALE + B_FEMALE_PT * FEMALE + B_AGE1_PT * AGE1 + B_AGE2_PT * AGE2 + B_AGE3_PT * AGE3 + B_AGE4_PT * AGE4 + B_AGE5_PT * AGE5 + B_AGE6_PT * AGE6 + B_LOWERTHANBSC_PT * LOWERTHANBSC + B_BSC_PT * BSC + B_MSC_PT * MSC + B_PHD_PT * PHD + B_CHILDREN_PT * CHILDREN + B_NOCHILDREN_PT * NOCHILDREN + B_CARUSER_PT * CARUSER + B_PTUSER_PT * PTUSER + B_SMUSER_PT * SMUSER + B_HAVECAR_PT * HAVECAR + B_NOCAR_PT * NOCAR + B_WORKING_PT * WORKING + B_STUDENT_PT * STUDENT + B_OTHERS_PT * OTHERS + B_COM_PT * COM + B_NONCOM_PT * NONCOM

V(AT) = B_AT_TIME * AT_TT_SCALED + B_safer_AT * AT_SAFETY_safer + B_AGE1_AT * AGE1 + B_AGE3_AT * AGE3 + B_BSC_AT * BSC + B_CARUSER_AT * CARUSER + B_PTUSER_AT * PTUSER + B_SMUSER_AT * SMUSER + B_HAVECAR_AT * HAVECAR + B_NOCAR_AT * NOCAR + B_WORKING_AT * WORKING

V(AFT) = B_AFT_COST * AFT_COST_SCALED + B_AGE3_AFT * AGE3 + B_AGE4_AFT * AGE4 + B_LOWERTHANBSC_AFT * LOWERTHANBSC + B_BSC_AFT * BSC + B_CARUSER_AFT * CARUSER + B_PTUSER_AFT * PTUSER + B_SMUSER_AFT * SMUSER + B_HAVECAR_AFT * HAVECAR + B_NOCAR_AFT * NOCAR + B_WORKING_AFT * WORKING + B_COM_AFT * COM + B_NONCOM_AFT * NONCOM

Appendix D: Survey Flyer and Questionnaires

Zukünftige Verkehrsmittelwahl in München
Future Transport Mode Choice in Munich



Wir laden Sie ein, an dieser Umfrage zur Verkehrsmittelwahl mit zukünftigen autonomen Verkehrsmitteln in München teilzunehmen:

http://www.bit.ly/uam-de

Die Umfrage dauert 15-20 Minuten und kann per Smartphone/Tablet/Computer beantwortet werden. Die Ergebnisse sind anonym und Teil einer Masterarbeit.

We invite you to take part in this survey about transport mode choice with future autonomous transport modes in Munich:

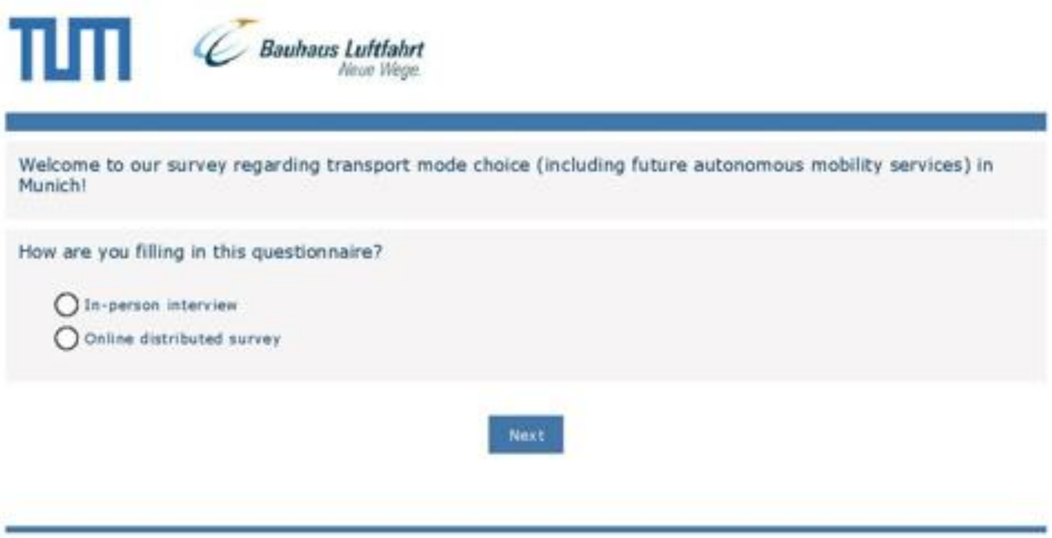
http://www.bit.ly/uam-en

The survey takes 15-20 minutes and can be answered via smartphone/tablet/computer. The results are anonymous and part of a master thesis.

mengying.fu@tum.de **bauhaus-luftfahrt.net**

Appendix D-1. Survey Flyer

Appendix D-2. Questionnaire (in English)


Welcome to our survey regarding transport mode choice (including future autonomous mobility services) in Munich!

How are you filling in this questionnaire?

- In-person interview
- Online distributed survey

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Do you frequently (more than 2 days per week) travel within Munich or Munich metropolitan region?

- Yes
- No

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Dear participant,

Thank you for your interest in our research.

My name is Mengying Fu and I would like to invite you to participate in a study which is part of my master thesis. My study is about transportation mode choice and future mobility in Munich, and it is supervised by the chair of Transportation Systems Engineering (Prof. Dr. Constantinos Antoniou) at the Technical University of Munich in cooperation with Bauhaus Luftfahrt e.V., a Munich-based aviation research institute.

We kindly ask you to take about 15-20 minutes to complete this questionnaire. Participation in this research study is completely voluntary. You have the right to withdraw at any time or refuse to participate entirely.

All information you provide will be kept confidential and will only be reported in an aggregate format (by reporting only combined results and never reporting individual ones). All responses will be handled anonymously.

In case of any concerns, please do not hesitate to contact me via email: mengying.fu@tum.de. Thank you very much for your support!

Mengying Fu

If you understand the above information and agree to participate in this study, please click "Next" to continue.

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TUM Bauhaus Luftfahrt Neue Wege

What is your **most frequently** used transport mode? (please select one only in terms of frequencies of trips)

- ◯ Private car (driver)
- ◯ Private car (passenger/car-pooling)
- ◯ Public transport (bus, tram, U-bahn, S-bahn in your region)
- ◯ On-demand car service (taxi)
- ◯ Bicycle
- ◯ Walk
- ◯ Other, please specify here [ ]

How many cars are available in your household?

- ◯ 0
- ◯ 1
- ◯ 2
- ◯ 3+

Do you have a driver's license?

- ◯ Yes
- ◯ No

How satisfied are you with your current way of traveling? Would you say you are...?

- ◯ Extremely dissatisfied
- ◯ Somewhat dissatisfied
- ◯ Neither satisfied nor dissatisfied
- ◯ Somewhat satisfied
- ◯ Extremely satisfied

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How much do you agree or disagree with each of the following statements regarding **your environmental concern**?

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree	I do not know
I am concerned about global warming.	○	○	○	○	○	○
I do not change my behaviour based on environmental concerns.	○	○	○	○	○	○
It is acceptable for an industrial society such as ours to cause some pollution.	○	○	○	○	○	○
I am willing to spend a bit more to buy a product that is more environmentally friendly.	○	○	○	○	○	○

How much do you agree or disagree with each of the following statements regarding **your technological concern**?

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree	I do not know
I am excited by the possibilities offered by new technologies to me.	○	○	○	○	○	○
I often use new technological products, even though they are expensive.	○	○	○	○	○	○
I have little to no interest in new technology.	○	○	○	○	○	○
New technology causes more problems than it solves.	○	○	○	○	○	○

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Please consider the following introduction to two new transport modes. The following questions will involve those two novel modes. There are no right or wrong answers. We are interested in your opinion.

This research focuses on two novel transport concepts: **Autonomous (self-driving) Taxi** and **Autonomous Flying (self-flying) Taxi**.

Below is a short description with similarities and differences between those two concepts.

Illustration of Autonomous Taxi:

Illustration of Autonomous Flying Taxi:

Comparison of the concepts:

Autonomous Taxi	Autonomous Flying Taxi
On-demand	
Trip reservation via smartphone app	
Pick-up and drop-off from/to your origin/destination	Pick-up and drop-off from/to a nearby „Vertiport"
Speed is the same as for conventional cars	Speed is 3 times higher than that of conventional cars
Carry up to 5 passengers	Carry up to 4 passengers
You would have the entire vehicle for yourself and your travel group	

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0% 100%

How much do you agree or disagree with each of the following statements regarding **your attitude towards autonomous technology enabled transport modes (such as autonomous taxi and autonomous flying taxi)**?

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree	I do not know
I would find it fun to use autonomous transport modes.	○	○	○	○	○	○
I have a fear of using self-driving taxi.	○	○	○	○	○	○
Autonomous transport modes should play an important role in our mobility system.	○	○	○	○	○	○
I have a fear of taking autonomous flying taxi.	○	○	○	○	○	○

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0% 100%

In the following, you will have the choice between four different transport modes for ***your 15 km regular commute (one-way)****. These scenarios are hypothetical and not necessarily realistic. We kindly ask you to choose your preferred mode of transport for each scenario. There are no right or wrong answers. We are interested in your opinion.*

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TUM Bauhaus Luftfahrt Neue Wege.

Please imagine that you are making a regular commuting trip for 15 km (one-way).

If these were your only options, which would you choose?

(1 of 6)

	Private car (driver)[1]	Public transport (bus, tram, U-bahn, S-bahn of the region)	Autonomous flying taxi	Autonomous taxi
Total travel time[2]	**30 Minutes**	**49 Minutes**	**21 Minutes**	**28 Minutes**
Total travel Cost/Fare	**5,25 €**	**5,80 €**	**75,00 €**	**11,00 €**
Safety level[3]	**Driving-level-safety**	**SAFER than driving**	**SAFER than driving**	**Driving-level-safety**
Inconvenience indicated by total walking time and/or waiting time	**2 Minutes**	**15 Minutes**	**10 Minutes**	**5 Minutes**
Multitasking possibility[4]	**No**	**In part**	**Yes**	**Yes**
	Select	Select	Select	Select

NONE: I wouldn't choose any of the above./I would take something different.

Select

Remarks:

[1] Total travel cost of **private car** includes *depreciation per km, fuel, insurance, tax, maintenance* etc; Parking will be available in both ends for **private car** travel, and parking cost is integrated into the travel cost

[2] **Total travel time** from door to door

[3] **Safer** means at least half the crash rate of driving; **Riskier** means double the crash rate of driving

[4] **Multitasking possibility** such as read and work

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0% 100%

Please imagine that you are making a regular commuting trip for 15 km (one-way).

If these were your only options, which would you choose?

(2 of 6)

	Autonomous flying taxi	Public transport (bus, tram, U-bahn, S-bahn of the region)	Private car (driver)[1]	Autonomous taxi
Total travel time[2]	21 Minutes	61 Minutes	30 Minutes	28 Minutes
Total travel Cost/Fare	15,00 €	2,90 €	9,75 €	9,00 €
Safety level[3]	Driving-level-safety	SAFER than driving	Driving-level-safety	Driving-level-safety
Inconvenience indicated by total walking time and/or waiting time	10 Minutes	19 Minutes	0 Minutes	10 Minutes
Multitasking possibility[4]	Yes	In part	No	Yes
	Select	Select	Select	Select

NONE: I wouldn't choose any of the above./I would take something different.

Select

Remarks:

[1] Total travel cost of **private car** includes *depreciation per km, fuel, insurance, tax, maintenance* etc; Parking will be available in both ends for **private car** travel, and parking cost is integrated into the travel cost

[2] **Total travel time** from door to door

[3] **Safer** means at least half the crash rate of driving; **Riskier** means double the crash rate of driving

[4] **Multitasking possibility** such as read and work

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0% 100%

TUM Bauhaus Luftfahrt Neue Wege.

Please imagine that you are making a regular commuting trip for 15 km (one-way).

If these were your only options, which would you choose?

(3 of 6)

	Private car (driver)[1]	Autonomous flying taxi	Autonomous taxi	Public transport (bus, tram, U-bahn, S-bahn of the region)
Total travel time[2]	**18 Minutes**	**21 Minutes**	**28 Minutes**	**49 Minutes**
Total travel Cost/Fare	**7,50 €**	**15,00 €**	**11,00 €**	**5,80 €**
Safety level[3]	**Driving-level-safety**	**RISKIER than driving**	**SAFER than driving**	**SAFER than driving**
Inconvenience indicated by total walking time and/or waiting time	**2 Minutes**	**5 Minutes**	**10 Minutes**	**19 Minutes**
Multitasking possibility[4]	**No**	**Yes**	**Yes**	**In part**
	Select	Select	Select	Select

NONE: I wouldn't choose any of the above./I would take something different.

Select

Remarks:
[1] Total travel cost of **private car** includes *depreciation per km, fuel, insurance, tax, maintenance* etc; Parking will be available in both ends for **private car** travel, and parking cost is integrated into the travel cost
[2] **Total travel time** from door to door
[3] **Safer** means at least half the crash rate of driving; **Riskier** means double the crash rate of driving
[4] **Multitasking possibility** such as read and work

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0% 100%

TUM Bauhaus Luftfahrt Neue Wege.

Please imagine that you are making a regular commuting trip for 15 km (one-way).

If these were your only options, which would you choose?

(4 of 6)

	Autonomous flying taxi	**Autonomous taxi**	**Private car (driver)**[1]	**Public transport (bus, tram, U-bahn, S-bahn of the region)**
Total travel time[2]	**21 Minutes**	**40 Minutes**	**42 Minutes**	**38 Minutes**
Total travel Cost/Fare	**75,00 €**	**9,00 €**	**7,50 €**	**2,90 €**
Safety level[3]	**SAFER than driving**	**Driving-level-safety**	**Driving-level-safety**	**SAFER than driving**
Inconvenience indicated by total walking time and/or waiting time	**5 Minutes**	**10 Minutes**	**4 Minutes**	**19 Minutes**
Multitasking possibility[4]	**Yes**	**Yes**	**No**	**In part**
	Select	Select	Select	Select

NONE: I wouldn't choose any of the above./I would take something different.

Select

Remarks:

[1] Total travel cost of **private car** includes *depreciation per km, fuel, insurance, tax, maintenance* etc; Parking will be available in both ends for **private car** travel, and parking cost is integrated into the travel cost

[2] **Total travel time** from door to door

[3] **Safer** means at least half the crash rate of driving; **Riskier** means double the crash rate of driving

[4] **Multitasking possibility** such as read and work

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0% 100%

Please imagine that you are making a regular commuting trip for 15 km (one-way).

If these were your only options, which would you choose?

(5 of 6)

	Public transport (bus, tram, U-bahn, S-bahn of the region)	**Autonomous taxi**	**Private car (driver)[1]**	**Autonomous flying taxi**
Total travel time[2]	**61 Minutes**	**28 Minutes**	**18 Minutes**	**17 Minutes**
Total travel Cost/Fare	**2,90 €**	**9,00 €**	**5,25 €**	**75,00 €**
Safety level[3]	**SAFER than driving**	**RISKIER than driving**	**Driving-level-safety**	**SAFER than driving**
Inconvenience indicated by total walking time and/or waiting time	**19 Minutes**	**5 Minutes**	**0 Minutes**	**7,5 Minutes**
Multitasking possibility[4]	**In part**	**Yes**	**No**	**Yes**
	Select	Select	Select	Select

NONE: I wouldn't choose any of the above./I would take something different.

Select

Remarks:

[1] Total travel cost of **private car** includes *depreciation per km, fuel, insurance, tax, maintenance* etc; Parking will be available in both ends for **private car** travel, and parking cost is integrated into the travel cost

[2] **Total travel time** from door to door

[3] **Safer** means at least half the crash rate of driving; **Riskier** means double the crash rate of driving

[4] **Multitasking possibility** such as read and work

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0% 100%

TUM Bauhaus Luftfahrt Neue Wege

Please imagine that you are making a regular commuting trip for 15 km (one-way).

If these were your only options, which would you choose?

(6 of 6)

	Private car (driver)[1]	Autonomous taxi	Autonomous flying taxi	Public transport (bus, tram, U-bahn, S-bahn of the region)
Total travel time[2]	42 Minutes	40 Minutes	17 Minutes	38 Minutes
Total travel Cost/Fare	7,50 €	13,00 €	75,00 €	1,00 €
Safety level[3]	Driving-level-safety	RISKIER than driving	RISKIER than driving	SAFER than driving
Inconvenience indicated by total walking time and/or waiting time	4 Minutes	10 Minutes	7,5 Minutes	15 Minutes
Multitasking possibility[4]	No	Yes	Yes	In part
	Select	Select	Select	Select

NONE: I wouldn't choose any of the above./I would take something different.

Select

Remarks:

[1] Total travel cost of **private car** includes *depreciation per km, fuel, insurance, tax, maintenance* etc; Parking will be available in both ends for **private car** travel, and parking cost is integrated into the travel cost

[2] **Total travel time** from door to door

[3] **Safer** means at least half the crash rate of driving; **Riskier** means double the crash rate of driving

[4] **Multitasking possibility** such as read and work

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0% 100%

In the following, you will have the choice between four different transport modes for ***a 15 km non-commute private trip (one-way), such as going to the airport, or travelling with the intention of performing recreational or social activities (e.g.attending a cultural/sport event, or visiting family/friends), etc****.*
These scenarios are hypothetical and not necessarily realistic. We kindly ask you to choose your preferred mode of transport for each scenario. There are no right or wrong answers. We are interested in your opinion.

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0% 100%

Please imagine that you are making a 15 km non-commute private trip (one-way), such as going to the airport, or travelling with the intention of performing recreational or social activities (e.g.attending a cultural/sport event, or visiting family/friends), etc.

If these were your only options, which would you choose?

(1 of 6)

	Private car (driver) [1]	**Public transport (bus, tram, U-bahn, S-bahn of the region)**	**Autonomous flying taxi**	**Autonomous taxi**
Total travel time [2]	**30 Minutes**	**49 Minutes**	**21 Minutes**	**28 Minutes**
Total travel Cost/Fare	**5,25 €**	**5,80 €**	**75,00 €**	**11,00 €**
Safety level [3]	**Driving-level-safety**	**SAFER than driving**	**SAFER than driving**	**Driving-level-safety**
Inconvenience indicated by total walking time and/or waiting time	**2 Minutes**	**15 Minutes**	**10 Minutes**	**5 Minutes**
Multitasking possibility [4]	**No**	**In part**	**Yes**	**Yes**
	Select	Select	Select	Select

NONE: I wouldn't choose any of the above./I would take something different.

Select

Remarks:

[1] Total travel cost of **private car** includes *depreciation per km, fuel, insurance, tax, maintenance* etc; Parking will be available in both ends for **private car** travel, and parking cost is integrated into the travel cost

[2] **Total travel time** from door to door

[3] **Safer** means at least half the crash rate of driving; **Riskier** means double the crash rate of driving

[4] **Multitasking possibility** such as read and work

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0% 100%

Please imagine that you are making a 15 km non-commute private trip (one-way), such as going to the airport, or travelling with the intention of performing recreational or social activities (e.g.attending a cultural/sport event, or visiting family/friends), etc.

If these were your only options, which would you choose?

(2 of 6)

	Autonomous flying taxi	**Public transport (bus, tram, U-bahn, S-bahn of the region)**	**Private car (driver)[1]**	**Autonomous taxi**
Total travel time[2]	**21 Minutes**	**61 Minutes**	**30 Minutes**	**28 Minutes**
Total travel Cost/Fare	**15,00 €**	**2,90 €**	**9,75 €**	**9,00 €**
Safety level[3]	**Driving-level-safety**	**SAFER than driving**	**Driving-level-safety**	**Driving-level-safety**
Inconvenience indicated by total walking time and/or waiting time	**10 Minutes**	**19 Minutes**	**0 Minutes**	**10 Minutes**
Multitasking possibility[4]	**Yes**	**In part**	**No**	**Yes**
	Select	Select	Select	Select

NONE: I wouldn't choose any of the above./I would take something different.

Select

Remarks:

[1] Total travel cost of **private car** includes *depreciation per km, fuel, insurance, tax, maintenance* etc; Parking will be available in both ends for **private car** travel, and parking cost is integrated into the travel cost

[2] **Total travel time** from door to door

[3] **Safer** means at least half the crash rate of driving; **Riskier** means double the crash rate of driving

[4] **Multitasking possibility** such as read and work

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Please imagine that you are making a 15 km non-commute private trip (one-way), such as going to the airport, or travelling with the intention of performing recreational or social activities (e.g.attending a cultural/sport event, or visiting family/friends), etc.

If these were your only options, which would you choose?

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	Private car (driver) [1]	**Autonomous flying taxi**	**Autonomous taxi**	**Public transport (bus, tram, U-bahn, S-bahn of the region)**
Total travel time [2]	**18 Minutes**	**21 Minutes**	**28 Minutes**	**49 Minutes**
Total travel Cost/Fare	**7,50 €**	**15,00 €**	**11,00 €**	**5,80 €**
Safety level [3]	**Driving-level-safety**	**RISKIER than driving**	**SAFER than driving**	**SAFER than driving**
Inconvenience indicated by total walking time and/or waiting time	**2 Minutes**	**5 Minutes**	**10 Minutes**	**19 Minutes**
Multitasking possibility [4]	**No**	**Yes**	**Yes**	**In part**
	Select	Select	Select	Select

NONE: I wouldn't choose any of the above./I would take something different.

Select

Remarks:
[1] Total travel cost of **private car** includes *depreciation per km, fuel, insurance, tax, maintenance* etc; Parking will be available in both ends for **private car** travel, and parking cost is integrated into the travel cost
[2] **Total travel time** from door to door
[3] **Safer** means at least half the crash rate of driving; **Riskier** means double the crash rate of driving
[4] **Multitasking possibility** such as read and work

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Please imagine that you are making a 15 km non-commute private trip (one-way), such as going to the airport, or travelling with the intention of performing recreational or social activities (e.g.attending a cultural/sport event, or visiting family/friends), etc.

If these were your only options, which would you choose?

(4 of 6)

	Autonomous flying taxi	Autonomous taxi	Private car (driver)[1]	Public transport (bus, tram, U-bahn, S-bahn of the region)
Total travel time[2]	**21 Minutes**	**40 Minutes**	**42 Minutes**	**38 Minutes**
Total travel Cost/Fare	**75,00 €**	**9,00 €**	**7,50 €**	**2,90 €**
Safety level[3]	**SAFER than driving**	**Driving-level-safety**	**Driving-level-safety**	**SAFER than driving**
Inconvenience indicated by total walking time and/or waiting time	**5 Minutes**	**10 Minutes**	**4 Minutes**	**19 Minutes**
Multitasking possibility[4]	**Yes**	**Yes**	**No**	**In part**
	Select	Select	Select	Select

NONE: I wouldn't choose any of the above./I would take something different.

Select

Remarks:
[1] Total travel cost of **private car** includes *depreciation per km, fuel, insurance, tax, maintenance* etc; Parking will be available in both ends for **private car** travel, and parking cost is integrated into the travel cost
[2] **Total travel time** from door to door
[3] **Safer** means at least half the crash rate of driving; **Riskier** means double the crash rate of driving
[4] **Multitasking possibility** such as read and work

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Please imagine that you are making a 15 km non-commute private trip (one-way), such as going to the airport, or travelling with the intention of performing recreational or social activities (e.g.attending a cultural/sport event, or visiting family/friends), etc.

If these were your only options, which would you choose?

(5 of 6)

	Public transport (bus, tram, U-bahn, S-bahn of the region)	**Autonomous taxi**	**Private car (driver)[1]**	**Autonomous flying taxi**
Total travel time[2]	**61 Minutes**	**28 Minutes**	**18 Minutes**	**17 Minutes**
Total travel Cost/Fare	**2,90 €**	**9,00 €**	**5,25 €**	**75,00 €**
Safety level[3]	**SAFER than driving**	**RISKIER than driving**	**Driving-level-safety**	**SAFER than driving**
Inconvenience indicated by total walking time and/or waiting time	**19 Minutes**	**5 Minutes**	**0 Minutes**	**7,5 Minutes**
Multitasking possibility[4]	**In part**	**Yes**	**No**	**Yes**
	Select	Select	Select	Select

NONE: I wouldn't choose any of the above./I would take something different.

Select

Remarks:
[1] Total travel cost of **private car** includes *depreciation per km, fuel, insurance, tax, maintenance* etc; Parking will be available in both ends for **private car** travel, and parking cost is integrated into the travel cost
[2] **Total travel time** from door to door
[3] **Safer** means at least half the crash rate of driving; **Riskier** means double the crash rate of driving
[4] **Multitasking possibility** such as read and work

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Please imagine that you are making a 15 km non-commute private trip (one-way), such as going to the airport, or travelling with the intention of performing recreational or social activities (e.g.attending a cultural/sport event, or visiting family/friends), etc.

If these were your only options, which would you choose?

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	Private car (driver) [1]	**Autonomous taxi**	**Autonomous flying taxi**	**Public transport (bus, tram, U-bahn, S-bahn of the region)**
Total travel time [2]	**42 Minutes**	**40 Minutes**	**17 Minutes**	**38 Minutes**
Total travel Cost/Fare	**7,50 €**	**13,00 €**	**75,00 €**	**1,00 €**
Safety level [3]	**Driving-level-safety**	**RISKIER than driving**	**RISKIER than driving**	**SAFER than driving**
Inconvenience indicated by total walking time and/or waiting time	**4 Minutes**	**10 Minutes**	**7,5 Minutes**	**15 Minutes**
Multitasking possibility [4]	**No**	**Yes**	**Yes**	**In part**
	Select	Select	Select	Select

NONE: I wouldn't choose any of the above./I would take something different.

Select

Remarks:

[1] Total travel cost of **private car** includes *depreciation per km, fuel, insurance, tax, maintenance* etc; Parking will be available in both ends for **private car** travel, and parking cost is integrated into the travel cost

[2] **Total travel time** from door to door

[3] **Safer** means at least half the crash rate of driving; **Riskier** means double the crash rate of driving

[4] **Multitasking possibility** such as read and work

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Assuming that taking an **autonomous flying taxi** would cost half as much as today's taxi fare and would also be faster and safer, then how likely would you choose **autonomous flying taxi** as your travel mode with regard to the following trip purposes?

	Very unlikely	Somewhat unlikely	Neither likely nor unlikely	Somewhat likely	Very likely	I do not know
Work (daily commute)	○	○	○	○	○	○
Business	○	○	○	○	○	○
Shopping	○	○	○	○	○	○
Recreational activities (e.g.attending cultural or sport events)	○	○	○	○	○	○
Education (e.g.going to school or university)	○	○	○	○	○	○
Social activities (e.g.visiting family or friends)	○	○	○	○	○	○

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Now the choice task part is completed and we would like to ask you some demographic questions.

What age range do you fit in?

- ◯ <18
- ◯ 18-25
- ◯ 26-35
- ◯ 36-45
- ◯ 46-55
- ◯ 56-65
- ◯ >65
- ◯ Prefer not to answer

What is your gender?

- ◯ Male
- ◯ Female
- ◯ Prefer not to answer

How many adults (18 years and older) live in your household?

- ◯ 1
- ◯ 2
- ◯ 3
- ◯ 4+
- ◯ Prefer not to answer

How many children (0-17 years old) live in your household?

- ◯ 0
- ◯ 1
- ◯ 2
- ◯ 3+
- ◯ Prefer not to answer

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What is your current employment situation?

- ◯ Employed – full time
- ◯ Employed – part time (11 to less than 35 hours/week)
- ◯ Apprenticeship
- ◯ Pupil (including pre-school)
- ◯ Student (university or college)
- ◯ Currently unemployed
- ◯ Temporary leave (e.g. maternity leave, paternity leave)
- ◯ Housewife or househusband
- ◯ Retiree
- ◯ Military or civil service, voluntary service
- ◯ Other
- ◯ Prefer not to answer

Please enter the postcode (zip code) of your home location (optional information)

Please enter the postcode (zip code) of your work or education location (optional information)

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What is the highest level of education you have completed?

- ◯ School without graduation
- ◯ Primary or secondary school
- ◯ High school
- ◯ Apprenticeship with graduation
- ◯ Bachelor's degree
- ◯ Master's degree
- ◯ Ph.D
- ◯ Prefer not to answer

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What is your household **net monthly income** in Euros (roughly)?

Please include all types of income, including monthly wage, salary, income from self-employment, pension, child allowance, housing benefit or social assistance, and other income after deducting taxes and social security contributions for all household members.

- ◯ Up to 500 €
- ◯ 500 to less than 1000 €
- ◯ 1000 to less than 2000 €
- ◯ 2000 to less than 3000 €
- ◯ 3000 to less than 4000 €
- ◯ 4000 to less than 5000 €
- ◯ 5000 to less than 6000 €
- ◯ 6000 to less than 7000 €
- ◯ More than 7000 €
- ◯ Prefer not to answer

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[23] The question regarding income was adapted from the survey question of Twaddle (2011).

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Would you like to comment on this questionnaire? Please leave us suggestions here.

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Thank you very much. We appreciate your contribution to our study!

If you have any questions or would like to get informed about the final results of the thesis project, please feel free to contact me through email:
mengying.fu@tum.de

If you are interested in the involved institutes, please see more information from:
Chair of Transportation Systems Engineering, Technical University of Munich:
http://www.tse.bgu.tum.de/en/home/ and Bauhaus Luftfahrt e.V.: https://www.bauhaus-luftfahrt.net

You can safely close the survey. Thank you very much.

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Declaration concerning the Master's Thesis

I hereby confirm that the presented thesis work has been done independently and using only the sources and resources as are listed. This thesis has not previously been submitted elsewhere for purposes of assessment.

Munich, June 4th, 2018

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Mengying Fu