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Exploration of Passenger Mode Choice Behaviour on Lisbon Airport

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Master in Management of Services and Technology

Supervisor:
Professor Sofia Kalakou, Assistant Professor, ISCTE Business School

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BUSINESS
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Resumo

Nos últimos anos, a procura de viagens aéreas tem aumentado significativamente, o que gera um maior volume de passageiros que se deslocam de e para os aeroportos. Têm surgido novos serviços de mobilidade a nível mundial, como o ride-hailing, ride-sharing e carsharing, que ofereceram novas soluções competitivas ao mercado. A quota crescente de Transport Network Companies como a Uber nos aeroportos afeta os respetivos serviços de estacionamento, que representavam uma fonte significativa de receitas para os aeroportos. Assim, é necessário analisar a decisão do meio de transporte dos passageiros, para assegurar os melhores serviços prestados pelas autoridades dos aeroportos e para esta indústria não seja afetada por outros operadores de transporte. Apesar de existir muita investigação sobre este tema, não foi encontrado um estudo de caso sobre o aeroporto de Lisboa na literatura e, especialmente, um estudo que inclua os novos serviços de mobilidade como a Uber. Assim, o principal objetivo deste trabalho é analisar o comportamento dos passageiros em Lisboa. Foi então realizado um inquérito para recolher informações sobre as características dos passageiros e das suas viagens para ou do aeroporto. Foram recolhidas 319 respostas, o que permitiu desenvolver modelos de escolha discreta e escolher as variáveis significativas. Verificou-se que as variáveis relacionadas com as características dos meios de transporte, da viagem e as características dos passageiros são significativas para explicar o comportamento de escolha do meio de transporte dos passageiros em Lisboa.

Palavras-Chave: Decisão do Meio de Transporte, Design do Inquérito, Modelos de Escolha Discreta, Meios de Acesso Terrestres, Serviços de Ride-Hailing, Aeroporto de Lisboa.

Abstract

In recent years, demand for air travel has increased significantly, which means more passenger volumes moving to and from airports. New worldwide mobility services such as ride-hailing, ride-sharing and carsharing have arisen and offered new market competitive solutions. The increasing market share of Transportation Network Companies like Uber at airports are negatively affecting parking services, which was a significant source of airport revenue. Therefore, it is necessary to explore the mode choice behaviour of air passengers in order to ensure that the best services are provided to airport authorities and this industry is not affected by other transport providers. Despite the amount of research conducted on the subject of airport mode choice, it was not found a case study on the Lisbon Airport in the literature and especially a study that includes new mobility services like Uber. The main goal of this work is thereby to explore the mode choice behaviour of air passengers in the Metropolitan Area of Lisbon. A survey to collect relevant information on the characteristics of passengers and their airport ground trips was conducted. A total of 319 answers were gathered, allowing to develop discrete choice models and choose significant variables. It was found that variables related to transport modes characteristics, trip and passenger characteristics are significant to explain the Lisbon's passenger mode choice behaviour.

Keywords: Mode Choice Behaviour, Survey Design, Discrete Choice Models, Ground Access Modes, Ride-Hailing Services, Lisbon Airport.

JEL classification: R4 Transportation Economics, C25 Discrete Regression and Qualitative Choice Models

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Acronyms

ABE	Lehigh Valley International Airport
ACY	Atlantic City International Airport
BDS	Brindisi Airport
BL	Binary logit
BRI	Bari International Airport-Karol Wojtyla
CMH	Port Columbus International Airport
DCM	Discrete Choice Modelling
EC	European Commission
EWR	Newark Liberty International Airport
FOG	Foggia Gino Lisa Airport
HIA	Hamad International Airport
HKIA	Hong Kong International Airport
HPN	Westchester County Airport
ISP	Long Island MacArthur Airport
IVTT	In-vehicle travel time
JFK	John F. Kennedy International Airport
LCC	Low-cost carriers
LGA	LaGuardia Airport
MMNL	Mixed logit
MNL	Multinomial logit
MXNL	Mixed nested logit
NL	Nested logit
OAK	Oakland International Airport
OVTT	Out-of-vehicle travel time
RUM	Random utility maximisation theory
SEM	Structural Equation Modelling
SFO	San Francisco International Airport
SJC	San Jose International Airport
SWF	New York Stewart International Airport

TAR	Taranto-Grottaglie Airport
TIA	Taoyuan International Airport
TNCs	Transportation Network Company's
TTN	Trenton-Mercer Airport
UK	United Kingdom
USA	United States of America

Symbols

n	Person from a population
C_n	Set of choices for each person
i	Alternative from a set of choices
$U_{i,n}$	Utility value
ε	Error constant
$P(i\|C_n)$	Probability of access mode choice
$V_{i,n}$	Deterministic component
β	Estimated parameter
N	Observations from a population
L	Likelihood function
$f(\varepsilon)$	Density of random component
$F(\varepsilon)$	Cumulative distribution
$t_{\beta'}$	t-statistic of the estimated parameter
X^2	Likelihood ratio test

1. Introduction

Before the coronavirus outbreak, international and domestic air travel demand have increased sharply every year. 2019 almost set a record of 4.6 billion air passengers and predictions suggested a number of 8.2 billion in 2037 (IATA - International Air Transport Association, 2018). However, due to the coronavirus pandemic, the number of scheduled air passengers dropped to only 1.8 billion people in 2020, which represents a 60 percent loss in global air passenger traffic (Mazareanu, 2020). Despite well below pre-crisis levels on many performance measures, the air transport sector is expected to recover with the open borders and rising demand in 2021 (IATA - International Air Transport Association, 2020).

The previous experienced growth in air travel industry has been largely driven by the rise of the low-cost carriers (LCCs), which lowered the cost of air trips and made them economically affordable to a larger share of the global population (Bergantino et al., 2019; de Neufville, 2006). LCCs have thereby opened new opportunities for foreign holidays and short breaks for those that have previously been excluded from air travel. Currently, travelling abroad once a year or more is feasible for the great majority of the developed world's population, and it has even become an embedded social practice worldwide (Shaw & Thomas, 2006). According to Travel Agent Central Website (2017), the *weekend getaway* trend is on the rise as more people have been planning short trips abroad on weekends to see friends and family or discover new places and escape from stress, news and social media.

The fast-growing demand for air travel means more air passengers, but also additional staff and accompanying persons needing to access the airport which generates an increase in ground access traffic and congestion (Bergantino et al., 2019). Coogan (2008), for instance, estimated that an airport handling 45 million passengers per year can generate up to 5 million vehicle miles of surface access travel per day (the equivalent of up to 1825 million miles per year). Ground traffic at and around airports have negative economic, safety, environmental, and social impacts such as noise, local air quality and increased gases emissions (Alhussein, 2011; L. Budd et al., 2016). According to Belobaba (2009), ground access is part of the overall trip and affects the passenger experience. Therefore, it is crucial for airport authorities to ensure proper airport ground accessibility that accommodate air travel growth while minimizing the related negative externalities (L. Budd et al., 2016). Indeed, past studies have shown that, in the same area, airports of high level of accessibility are more competitive, which means airport accessibility is a source of competitive advantage over neighbouring airports (Bao et al., 2016; Hess & Polak, 2006).

Given the growth in air travel market and increase in competition, policy makers and regional mobility planners are also engaged on ensuring easy airport ground access to leverage local tourism development and competitiveness (Liu et al., 2013). The European Commission (EC) set the following high-level objectives for a seamless air mobility in 2050 across the European countries: "…*90% of the travels involving air transport within Europe can be completed in 4 hours door to door; passengers can make informed decisions; air transport is well connected to other modes.*" (European Commission, 2015). To achieve seamless door to door mobility, i.e. from the origin of the trip to the final destination of the journey by airplane, airport and transport operators must collaborate to provide a more integrated multimodal transport system and shorten travel time. The Frankfurt Airport, for instance, is considered a best practice in easy and convenient air-rail multimodal transportation for many decades (Costa, 2012; Payne, 1999). The Lufthansa Express Rail service is a joint venture of Lufthansa, Deutsche Bahn and Fraport that facilitates the connection between a high-speed train with flights to and from the Frankfurt Airport, as seamlessly as possible and at optimal transfer times. The passengers receive just one ticket for both train and Lufthansa flight and can check-in online or by mobile phone (Costa, 2012; Frankfurt Airport - Lufthansa Express Rail, 2019; Lufthansa Express Rail, 2019).

The digital transformation and servitization of the mobility sector are ongoing and have already enabled new worldwide mobility services, including ride-hailing, ride-sharing, bike-sharing and carsharing (Xie et al., 2019). A very successful example is Uber which has disrupted the transportation industry and changed the way people move by introducing real-time peer-to-peer ride-hailing through a smartphone app (Fioreze et al., 2019). 10 years after its launch, Uber operates in more than 800 cities with 15 million completed rides a day across the globe (Vardhman, 2019). For air passengers, these new mobility solutions improve the air travel experience by personalizing their ground access choice at reduced cost. For airports, such trends are starting to harm their financial performance and infrastructure investment decisions (Streeting et al., 2018). The increasing market share of Transportation Network Company's (TNCs) like Uber at airports are negatively affecting parking services, which was a significant source of airport revenue since the beginning of mass commercial aviation more than 70 years ago (Streeting et al., 2018; Martin, 2019). In 2018, around 15% of Uber's worldwide ridesharing gross bookings were generated from trips that drivers either started or completed at an airport (O'Neill, 2019). In contrast, initial findings from San Francisco, Denver, Portland and Kansas City airports, show an annual declining rate range of 3% to 7% on parking revenues per passenger one or two years after the emergence of TNCs in 2012 (Henao et al., 2018). Equally, the Fresno Yosemite International Airport, in California, is losing an estimated $180,000 a year in parking revenue because of TNCs growth (Bergal, 2017). Therefore, it is crucial for airports to appropriately monetize TNCs access and start offering competitive mobility solutions, otherwise they will be left with a revenue gap (Streeting et al., 2018).

Given the scale, complexity and importance of ground accessibility, its strategic planning is currently a major priority for airport authorities, policy makers and regional mobility planners. Although ground access incorporates a range of different user groups, passenger access demands a greater attention since they represent the airport's primary customers and the highest volume of trips generated (including additional journeys for dropping-off/picking-up passengers). Ground access mode choice of this group depends first on the available options, as well as on time constraints, cost, travel party size, among others (Kamga et. al., 2012). To meet the ground accessibility needs of air passengers, the managers concerned must first understand the several different factors affecting access mode decision making. In fact, the behaviour of air passengers concerning ground access modes has been analysed in many studies worldwide for several decades. Previous studies have focused on gathering the important factors affecting access mode choice at a specific area/city/airport per se, or to estimate the impact of the introduction of a new access mode or even to predict behavioural changes in a relocated airport.

Even though there are a lot of research on this topic, to the author's knowledge there is no published study on the mode choice behaviour of air passengers in Lisbon, Portugal. The present dissertation thereby aims to expand the current literature on airport access mode choice models by assessing the passenger behaviour of the Lisbon Airport. Besides that, also distinguishes itself from previous work by considering for the first time TNCs like Uber in the set of access mode alternatives. The obtained empirical data can be used to inform current practice and make recommendations for the future.

1.1. Objectives

The main goal of this dissertation is to explore the passenger mode choice to access the Lisbon Airport. In order to reach this objective, two research questions were posed to answer in this thesis:

1. What are the aspects that have been identified in the literature to affect air passenger mode choices?
2. What aspects affect the passenger mode choice in the case of Lisbon Airport?

1.2. Methodology

To accomplish the objective previously mentioned, the first step was the creation of the survey, which contains questions about the passengers socioeconomics characteristics and their last air travel. This allowed to understand the passenger mode choice and to model them. Considering the results of the survey, a choice dataset was defined using three transportation mode variables: car, public transportation and ride-hailing services. Finally, a discrete choice model was modelled, which in this case was the multinomial logit model.

1.3. Thesis Outline

The present work is divided into five chapters. The first chapter intends to inform the reader about the problem addressed in this thesis, as well as the motivation and the main objectives of this work.

Chapter 2 introduces the concept of airport accessibility and provides a resume of all the relevant work found in the literature regarding this topic.

Chapter 3 presents a detailed description about the methodology followed in this work, beginning with the description of the survey. The method used in this dissertation to analyse the passenger mode choice behaviour is then explained, introducing three of the most common models. Finally, a description of the research context is presented.

In Chapter 4, it is first exhibited the survey statistical results. Then, the estimated discrete choice models are presented and explained. Last, the main results are discussed and compared with literature.

Chapter 5 includes the final conclusions of this study, along with its limitations and suggestions for future work.

2. Literature Review

Geurs and Wee (2004) define accessibility as "*… the extent to which land-use and transport systems enable (groups of) individuals to reach activities or destinations by means of a (combination of) transport mode(s)*". Accordingly, airport ground accessibility describes "*… how people, goods and vehicles access and egress airports by non-aeronautical based modes of transport*" (L. Budd et al., 2016). Essentially, it is specifically related with the trip to and from the airports. The higher level of airport accessibility indicates that the airport landside transportation facilities are more carefully designed, and airport users can access to the airport more conveniently.

2.1. Air passenger access mode choice behaviour

Several authors proved the relevance of ground accessibility for airport competition and its overall attractiveness over rivals (Gupta et al., 2008). According to Bao et al. (2016), passenger traffic of an airport would increase by 2% if the level of accessibility is improved by 1%. With the fast-growing demand for air travel, passenger mode choice behaviour has therefore been largely investigated by practitioners.

In general, there are several ground transport options for traveling to and from the airport including public transport, hotel shuttles, taxicabs, rental cars, and private cars or car services. As previously mentioned, passenger choices depend first on the available options, as well as on various trip and personal characteristics. Understanding the link between these factors and passenger preferences of ground access is therefore a key aspect to improve airport ground transportation system.

The earliest studies on modelling accessibility to airports dates to the 1970s and since then, several others have continuously been published over time. The literature mainly relies on case studies using surveys conducted at the airports or via internet to collect data on travellers and their trip characteristics. The choice set usually includes transport modes already available in the region or airport under analysis, even though some studies also assess the introduction of a new alternative. Access decisions are then modelled by exploring multiple variables and developing different discrete choice (statistical) models to quantify the relative importance of various factors affecting the decision. It is worth of mention that Pamucar (2020) have recently published a study on airport ground access mode decision making where it considers for the first time Uber in the alternatives set. However, instead of discrete choice models, the author used a hybrid fuzzy multi-criteria decision-making method.

Most researched adopted the approach of market segmentation to better define travel parameters and preferences for sets of passengers. The most common distinction is between business and non-business travellers since trip purpose (leisure) positively affects the choice of taking buses and negatively affects the use of cars (Choo et al., 2013). According to Gosling (2008), residents must be distinguished from visitors because the former typically have access to a private vehicle or can be dropped-off/picked-up at the airport by someone they know. A few authors have jointly modelled access decisions with airport and/or airline decisions or focused on studying the mode choice behaviour of elderly or disabled people, for example. In general, there are many published articles that tried to gather the important variables influencing passenger mode choice behaviour. In the following sections the research carried out up to date is presented and the main conclusions on this matter.

2.1.1. Trip characteristics

Regarding alternative-specific attributes, access travel time and cost have been reported in all existing studies as two of the most significant factors influencing the choice of access mode. The literature shows that these two parameters negatively affect the choice of a specific transport mode, that is, the higher the cost and travel time, the less likely the passengers to choose it. Amongst the first authors interested in this topic, Harvey (1986) modelled air passengers' behaviour in the San Francisco Bay area, United States of America (USA). The author adopted a segmentation into business and non-business travellers and developed separate multinomial logit (MNL) models for each segment. The results revealed that access travel time and cost were highly significant for both type of passengers; however, business travellers were considerably more sensitive to access time than non-business travellers. This explained why business travellers were more likely than non-business travellers to drive or take a taxi rather than taking the public transport (Choo et al., 2013; Harvey, 1986). These findings are corroborated by the work of Pels et al. (2003) also in the San Francisco Bay area. By developing a nested logit (NL) model to estimate the combined access mode-airport-choice, they found that access time played a more important role in the business travellers' joint choice.

Indeed, travel time has been pointed out by many authors as the main variable negatively influencing the use of public transport to access the airport. The paper of Jou et al. (2011), for example, showed the extent to which an improvement in the travel time of public transportation can reduce the market share of private vehicles and taxis to access the Taoyuan International Airport (TIA) in Taiwan. On the contrary, although the perception towards access cost does not greatly differ between business and non-business travellers, the literature implies the latter are more sensitive to cost and thereby more likely to be dropped-off or to take public transport (Harvey, 1986; Akar, 2013). This may due to the fact that travel expenses of business passengers are generally reimbursed by their company whereas those of non-business passengers are not (Chebli & Mahmassani, 2002; Birolini et. al, 2019).

Additionally, Birolini et. al. (2019) have recently highlighted the importance of travel time and cost for low cost airline passengers. The authors employed a mixed logit (MMNL) model to analyse the behaviour of outgoing passengers at the Milan-Bergamo airport and evaluated their time and cost sensitivity. Their findings showed that even though cost was the most important factor when accessing low cost airports, managers should not simply aim to deliver the solution with the lowest possible cost since access time is also important for the access mode choice.

The impact of access travel time is driven even further by the research of Tam et al. (2008) on time reliability. According to them, a lower travel time reliability may result in arriving late at the airport and a potentially high personal penalty on travellers if flights are missed. Since travellers cannot predict the exact travel time, they allow extra time when making a mode choice which is generally referred as a safety margin. Different access modes have different travel time reliability and therefore different safety margin measures. This means that the larger the safety margin, the less reliable the passenger perceives the mode to be. With the use of a MNL model, the authors quantify the effects of safety margin allowances on ground access mode choices to Hong Kong International Airport (HKIA). Their findings reveal that travel time reliability is a critical variable affecting the mode choice of air passengers, though business travellers tend to place a larger safety margin than non-business travellers. The significance of reliable access to airports is also highlighted in Akar (2013), who examined access transport options and the potential for alternative modes at the Port Columbus International Airport (CMH) in Ohio. Based on the analysis of the estimated binary logit (BL) models, reliability on time service was the most important factor for both business and non-business travellers when considering an alternative mode other than the automobile.

The importance of these attributes reaches a consensus with managers as well, but studies differ in the extent to which travel time and sometimes cost are broken down into different components and in the way they are later included in the models. Typically, time is separated into in-vehicle travel time (IVTT) and out-of-vehicle travel time (OVTT), which includes different elements. Harvey (1986), for instance, combined waiting and walking time into OVTT, whereas Jou et al. (2011) adopted a combination of walking and transfer time in their MMNL of mode choice in Taiwan. Besides IVTT and OVTT, Bergantino et al. (2020) also considered headway time (i.e., the time between two consecutive public transport services) to model airport accessibility in Apulia, Italy.

On the other hand, cost is not usually split into several components but is given by the sum of various aspects. The literature commonly considers travel cost as the total amount outlaid for the trip, including fuel cost, highway tolls, parking fees, and the ticket price for public transport (Birolini et al., 2019; Jou et al., 2011). In addition to these components, Bergantino et al. (2020) also considered the number of passengers to calculate the travel cost of car alternatives (car driver, car passenger, and taxi). They argued that by splitting amongst passengers, the travel cost of these modes may be lower in absolute terms when compared to other modes. This attribute is therefore included in the estimation models of car alternatives in the following way:

$$Travel\ Cost = \frac{travel\ cost}{1 + \ln\,(party\ size)} \tag{2.1}$$

Besides travel time and cost, other factors were found to be significant in explaining airport accessibility choices. As stated above, the size of the ground access travel party is taken into consideration when modelling passenger behaviour. Gupta et al. (2008) found that party size played an important role in the joint airport and ground access choice model for travellers in the New York metropolitan region. Similar results have been reported by Zaidan and Abulibdeh (2018), who explored mode choices for the Hamad International Airport (HIA) in Doha, Qatar in the face of the 2022 FIFA World Cup. They developed BL models to the current access mode choice, as well as MNL models to the future choice after introducing the Doha Metro. Their study revealed a strong association not only between the size of the party and mode choice currently used, but also when considering using the Doha Metro in the future. The probability of choosing a private vehicle over public transit increases when the party grows larger, whereas passengers are willing to use the Doha Metro if their party size is small.

The same conclusions apply to the amount of luggage passengers are carrying. Harvey (1986) and Akar (2013) stated that the number of bags negatively affects the utilization of public transport and increases the probability of choosing a private vehicle. According to Zaidan and Abulibdeh (2018), the number of bags is also considered an obstacle in using Doha Metro in the future. On the contrary, the work of Budd et al. (2014) indicates that passengers with checked-in luggage tend to use public transport more often to access airports. Moreover, the size of the ground access travel party and the amount of luggage passengers are carrying seem to be more important for non-business travellers, which can be explained by the fact that business travellers usually travel alone and with less luggage (Akar, 2013).

Finally, the literature also mentions trip duration as another variable determining the airport ground access mode. The work of Psaraki and Abacoumkin (2002) demonstrated that passengers favour the private car to access the Athens International Airport for short duration trips. The reason behind can be that the cost of drive and park mode is directly related with the number of days travellers are away from home. Since usually non-business travellers make longer trips, it is expected they choose other alternatives over drive and park mode (Harvey, 1986).

2.1.2. Personal characteristics

Alongside with the previously mentioned trip characteristics, many studies have reported the importance of personal characteristics for airport accessibility choices. Yet, the literature indicates that airport accessibility choices of non-business passengers are significantly more affected by demographic characteristics than those for business passengers (Choo et al., 2013). Residence status of passengers has been widely pointed out as a strong explanatory variable, as some researchers estimate separate models for residents and visitors (Gosling, 2008). According to Psaraki and Abacoumkin (2002), Athens residents strongly favour private car since they are more likely than visitors to have their own car, or to know someone who can drop them off to the airport. By contrast, Tam et al. (2008) reports that Hong Kong residents have a higher tendency to be transported by public transit when compared to visitors because they are more familiar with the local transport system.

Curiously, Gupta et al. (2008) reveals that gender tends to influence the joint airport-ground access mode choice in the New York City metropolitan region. Based on the analysis, female travellers are less likely to drive for both business and non-business trips. Female passengers travelling for non-business purposes are also less likely to use public transit options, which the authors suggest may be because they are often accompanied by children. Similar conclusions had been reported many years earlier by Harvey (1986), who concluded women favour the drop-off and taxi modes to access airports. However, the work of Akar (2013) and Zaidan and Abulibdeh (2018) contradict the previous findings. In both studies, gender was not a significant factor when modelling access mode choices. Zaidan and Abulibdeh (2018) believes that the culture and regulations of Qatar may explain it since women in this country are not usually allowed to travel alone, particularly abroad.

In addition to the residence status and gender, age also typically plays a significant role in airport ground access mode choice. Air passengers aged above 65 prefer private vehicles or taxis over public transports (Tam et al., 2008), whereas younger than 35 people prefer transit, taxis, and shared rides (Gupta et al., 2008). Zaidan and Abulibdeh (2018) have recently reported a different conclusion: the age group of 18 to 24 registers the highest dependency on the car mode to travel to the airport, in Qatar. A very interesting study on this matter is that of Chang (2013), who specifically analyzed the elderly air passenger choices when accessing Taipei International Airport, in Taiwan. As expected, the elderly passengers revealled a greater willingness to use private transport, particularly asking family members to drop them off at the airport rather than taking public transport. The results also indicated that safety, user friendliness and convenience for storing luggage were the most important factors in the mode choice of the elderly.

Age, income and nationality are another three socioeconomic characteristics that must be considered in every statistical model of passenger behaviour. Younger people tend to use other alternatives more often than driving and parking mode, which is also supported by their typically lower incomes when compared to older passengers (Gupta et al., 2008; Tam et al., 2008). On the other hand, Zaidan and Abulibdeh (2018) reveals a high car usage rate of

Qataris (i.e., a native of Qatar) to travel to the airport, which can be a result of their high incomes and strong culture of using cars in their daily lives. The same results were found in the previous study of Alhussein (2011) on Saudi Arabia's native air passengers, a neighbouring country.

The above-mentioned research has largely focused on the socioeconomic characteristics of travellers influencing airport ground access decisions instead of an individual’s attitudes or psychological viewpoint. McFadden (1986) was probably the first arguing the importance of including latent psychological variables regarding service performance and traveller satisfaction for a deeper understanding of travel mode choices. Some researchers have considered this approach by introducing an attitudinal variable measuring satisfaction level of access modes in their choice models (Kitamura & Mokhtarian, 1997; Tam et al., 2010). In the work of Tam et al. (2010), passengers ranked their satisfaction level towards the mode choices to access HKIA, in Hong Kong, based on the following five service attributes: waiting time, IVTT, travel time reliability, travel cost, and walking distance to and from public transport stations and/or car parks. Consecutively, they used a Structural Equation Modelling (SEM) approach to construct a satisfaction latent variable which is then incorporated in the discrete choice model as an explanatory variable. The analysis found that the satisfaction latent variable dominates all the other variables, which supports the premise that the level of satisfaction towards access modes had a major influence on the passenger mode choice behaviour.

2.2. Airport employees

The literature is extensive on airport accessibility choices of passengers since they represent the airport’s primary customers and highest volume of trips generated. However, it must be borne in mind that a large share of airport ground access trips is generated by airport employees. Major airports operate twenty-four-seven, providing tens of thousands of jobs and with each employee travelling both ways. Janic (2011) believes that the number of daily employees at the Amsterdam Schiphol Airport could reach 110 000 by the year of 2025-2030, which amounts to almost 13% of the total annual number of air passengers (80-85 million). Even though it has been given very little attention to airport employee mode choice, there are a few relevant works on this matter.

The research of Humphreys and Ison (2005) revealed that the percentage use of private vehicle at United Kingdom (UK) airports is considerably higher for employees than for passengers. They suggested it may be due to the typical shifts with unusual hours and workdays, which makes public transport a less attractive option. In the authors’ view, subsidized public transit and shared-rides, or improved rail and bus services may decrease employee dependency on private car. Another possible strategy to discourage employee car usage was a direct employee parking charge unlike the generally free parking provided by airport managers (Aldridge et al., 2006; Ison et al., 2007).

Finally, Tsamboulas et al. (2012) also focused on airport employees commuting mode choice at Athens International Airport. Like other studies, the results find that private car dominates employees' behaviour. Based on the estimated MNL model, employees are sensitive to travel time, travel cost and their income when selecting the transport mode. According to the authors, a metro rail service with competitive travel times and costs may thereby reduce employee dependency on the private car for airport trips.

Table 2.1, shown below, presents an overview of the studies previously described and their findings on explanatory variables.

Table 2.1 - Example of studies of passenger airport access mode choice.

Reference	Research Context	Sample Size	Mode Choice Set	Significant Variables	Model
Harvey (1986)	San Francisco Bay Area, US (SFO, OAK and SJC)	1850	Drive; Drop-off Transit; Airporter; Taxi	Travel time; Auto access to transit; Travel Cost; Drop-off passenger time; Luggage; Household size; Departure from home; Trip duration	MNL
Psaraki and Abacoumkin (2002)	Athens International Airport in Greece	15764	Drive and park; Lift and accompanied; Drop-off; Taxi; Public bus; Tourist buses; Rental cars	Residence status; Trip purpose; Trip destination	Hetero-scedastic extreme value models, MNL and random parameter models
Gupta et al. (2008)	New York and New Jersey Area, US (JFK, LGA, EWR, SWF, Macarthur ISP, HPN, ACY, ABE, TTN)	19127	Auto drop-of; Auto-Park; Taxi and limos; Shared vans, shared limos, and hotel courtesy vehicle; Rental cars; Rail; Local buses; Chartered buses	Travel time; Travel cost including transit fare daily; Daily airport parking rate; Resident or visitor; Gender; Age group; Household income group; Travel party size	MNL and NL
Jou et al. (2011)	Taoyuan International Airport (TIA) in Taiwan	540	Self-driving; Pickup; Taxi; Public Bus; High Speed Railroad; Mass rapid transit system	Out-of-vehicle travel time; In-vehicle travel time; Overall time-savings; User-friendly nature of the mode	MMNL
Choo et al. (2013)	Gimpo Airport and Daegu Airport, Korea	2290	Car; Taxi; Bus; Subway	Travel time; Travel distance; Trip purpose; Age; Gender; Occupation; Income	Logistic regression models
Zaidan and Abulibdeh (2018)	Hamad International Airport (HIA) in Doha, Qatar	1546	Park at airport; Drop-off; Van; Taxi; Metro; Bus	Number of travelers; Number of bags; Trip purpose; Cost; Journey time; Class categories; Re- imbursement of parking fees; Nationality; Average monthly household income; Employment status; Vehicle ownership; Age	BL and MNL
Birolini et al. (2019)	Milan-Bergamo Airport, Italy	2445	Car; Drop-off; Taxi; Bus; Train	Gender; Age; Trip purpose; Travel Party Size; Total Cost; In-vehicle travel time; Out-of-vehicle travel time; Traffic Index; Level of service	MMNL
Bergantino et al. (2020)	Apulia Area, Italy (BRI, BDS, FOG and TAR)	1229	Train; Bus; Car; Airport shuttle; Drop-off; Taxi	Out-of-vehicle travel time; In-vehicle travel time; Travel Cost; Gender; Age; Baggage; Education; Air Party Size	NL, MMNL and MXNL

3. Methodology

This chapter describes in detail the methodology followed in this work. First, a description of the survey design is provided. Furthermore, the discrete choice modelling process is explained to better understand the subject under study. Last, the research context of this dissertation is presented, which in this case is the Lisbon Airport. Figure 3.1 presents an overview of the approach followed in this thesis.

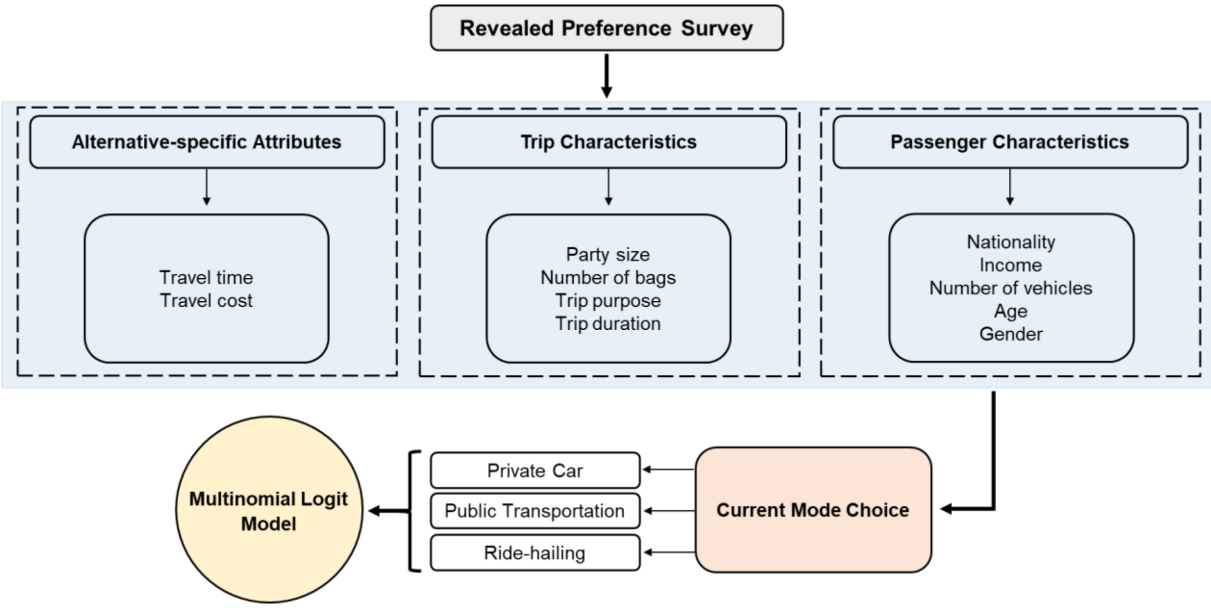

Figure 3.1 – Theoretical framework.

3.1. Survey design

As mentioned in the previous chapter, understanding which factors influence passenger ground access preferences and choices helps providing better airport ground transportation systems. Similar to most authors, a questionnaire survey was developed to collect quantitative descriptive data on Lisbon Airport passengers and thereby estimate modelling behaviour. It was an anonymous revealed preference web-based survey designed on LimeSurvey and allowed to divide respondents in two groups: departure and arrival passengers. Since usually passengers on transfer flights remain in the airport, those respondents were not considered and were immediately directed to the end of the survey. All survey questions for departing and arriving passengers are presented in Appendix A.1.

The survey consisted in the following 4 sections:

- **Section A:** general questions regarding passenger residential country, the destination or origin city of their flight, the purpose of the trip, which airline company they travelled with, and other general questions.

- **Section B or C:** questions about the ground trip to/from the airport which allow to get to know which alternative mode was chosen and collect information on two very relevant choice influencing factors, that is travel time and cost. Section B concerns to arrival passengers and their trip from the airport, whereas Section C concerns to departing passengers and their trip to the airport.
- **Section D:** questions regarding several trip characteristics to better understand passenger choice such as party size, number of bags, if the passenger used business lounge or fast track service, the weather conditions, time in advance they arrived at the airport (departing passengers), etc.
- **Section E:** personal questions to gather the passenger socioeconomic characteristics, such as age, gender, city of residence, monthly income, air travel frequency, number of vehicles they own, among many others.

The first survey version was pre-tested before being launched with around 30 random respondents. The purpose was to test all aspects of the questionnaire, including question content, wording, sequence, form and layout, question difficulty, and instructions. After a significant revision of the questionnaire, another pre-test was conducted using the same sample size but different respondents. The third and final version was then officially launched.

3.2. Discrete choice models

Discrete choice models (DCM) are widely used to analyse airport accessibility decisions. Fundamentally, these models are used to explain or predict access mode choices from a set of limited, distinct and mutually exclusive alternatives. Among the many discrete choice models, MNL is the most widely used. In this section, the standard estimation technique of MNL model is explained.

3.2.1. Multinomial logit model

Since proposed by McFadden (1974), discrete choice models are commonly derived from the random utility maximisation theory (RUM). According to the RUM concept, an individual derives a certain benefit from each alternative i of a set of choices ($C_n = 1, 2, 3, \ldots, n \wedge n \in N$) that is quantified by an utility value (U) and a rationale decision maker chooses the alternative that maximises his utility. However, part of the utility value is uncertain due to the lack of complete information, unobserved alternatives or characteristics, measurement errors and the utility function must include an error constant (ε) to capture these random components (Train, 2002). Given this, the choice process becomes probabilistic, and the probability of any access mode choice is given by:

$$P(i|C_n) = Pr\left(U_{i,n} \geq U_{j,n}, \forall j \in C_n\right) \tag{3.1}$$

Where $U_{i,n}$ is the utility of alternative i for person n and can be distinct in a deterministic component ($V_{i,n}$) and a random component ε as:

$$P(i|C_n) = Pr\left(V_{i,n} + \varepsilon_{i,n} \geq V_{j,n} + \varepsilon_{j,n}, \forall j \in C_n\right) \tag{3.2}$$

Where:

$$V_{i,n} = \sum_k \beta_k \cdot x_{i,n,k} \tag{3.3}$$

And x is a vector of explanatory variables, that is the attributes of the alternatives, the trip and personal characteristics influencing the decision. The impact of each variable for the choice is measured by the statistical significance of the estimated parameter β. These parameters are fixed values and are usually estimated from a (random) sample of N observations from the population by using the maximum likelihood estimation procedure. This procedure involves developing a joint probability density function of the observed sample, known as the likelihood function (L), and estimate the parameter values that maximise this function. The likelihood of the sample in total (L) is the product of the likelihood of all individual observations and can be defined as:

$$L(\beta) = \prod_{n=1}^{N} \prod_{i=1}^{J_{Cn}} P_n(i \mid C_n)^{y_{i,n}} \tag{3.4}$$

Where J_{C_n} is the size of the choice set, P_n is a function of $\beta_1, \beta_2, \dots, \beta_k$ and $y_{i,n}$ represents the decision-maker n choosing alternative i ($y_{i,n} = 1$ if i is chosen by individual n and $y_{i,n} = 0$ otherwise). Analytically, it is more convenient to consider the logarithm of the likelihood function ($logL$):

$$\log L(\beta) = \sum_{n=1}^{N} \sum_{i=1}^{J_{Cn}} y_{i,n} \cdot ln(P_n(i \mid C_n)) \tag{3.5}$$

The $logL$ is then solved to maximize it by just equating it to zero with respect to the β's (i.e., solve max $logL(\hat{\beta}_1, \hat{\beta}_2, \cdots, \hat{\beta}_k)$. The optimal solution is not so straightforward, and the computational burden grows with the number of alternatives, so it is generally obtained by using a computer software.

The random components $\varepsilon_{n,j}$ are assumed to be independently and identically Extreme Value (Gumbel) distributed across travellers and alternatives. This means that the relative probabilities of each pair of alternatives are independent of the presence or characteristics of all other alternatives (Train, 2002). The density $f(\varepsilon)$ of each random component is defined by:

$$f(\varepsilon_{n,j}) = e^{-\varepsilon_{n,j}} \cdot e^{-e^{-\varepsilon_{n,j}}} \quad (3.6)$$

And the cumulative distribution $F(\varepsilon_{n,j})$ is given by:

$$F(\varepsilon_{n,j}) = e^{-e^{-\varepsilon_{n,j}}} \quad (3.7)$$

Given this, the choice probabilities can be expressed in its logistical form as:

$$P(i|C_n) = \frac{e^{\beta' x_{i,n}}}{\sum_{j \in C_n} e^{\beta' x_{j,n}}} \quad (3.8)$$

The model specification process can be divided in three main steps. At first, a model with only those variables that are alternative-specific attributes will be estimated (that is, travel time and cost.). After that, several generic trip characteristics such as trip purpose, number of bags, party size and many others will be included and tested. Lastly, it will be introduced the various socioeconomic variables to test whether, for example, the respondent's gender, age or income has any impact in the model.

For each specification test, several aspects should be analysed in order to check the variables and model structure suitability. In this dissertation, a qualitative evaluation will be first carried out on the estimated parameter sign and the asymptotic t-test will be then performed to check the specification of the model. This test is used to check the validity of a certain null hypothesis with a significance level of 5%, i.e. the probability of rejecting this hypothesis with a 95% confidence level. In this case, the null hypothesis claims that a specific estimated parameter is equal to zero, meaning that it must be rejected in order to consider the related variable as explanatory. For that, the t-statistic associated to each parameter must be calculated by:

$$t_{\beta'} = \frac{\beta' - \beta_0}{\sigma_\beta} \quad (3.9)$$

Where β' is the estimated value of the parameter, β_0 is zero and σ_β is the standard error. The t-statistic values associated with a significance level of 5% are the interval of values lower than -1.96 and bigger than +1.96. The probability of obtaining a $t_{\beta'}$ with the sample results as the $t_{\beta'}$ from the null hypothesis is determined by the p-value. This means that if the p-value is greater than the chosen significance level ($p - value$ > 0.05), then the null hypothesis is failed to be rejected or, in other words, the variable under study does not contribute to explain the decision-maker choice.

Besides the t-test, a likelihood ratio test will be performed to check whether there is a significant improvement in the goodness-of-fit of the model after introducing a new explanatory variable. This test is based on the ratio of the restricted and enriched models' likelihood values. For that, all coefficients from the restricted model are set to zero, except for the alternative-specific constant (explained in Section 4.2.1.), and the following equation must be solved:

$$X^2 = -2 \cdot [LL_U - LL_R] \tag{3.10}$$

Where LL_U stands for the log likelihood of the enriched model and LL_R the log likelihood of the restricted one. At last, it is verified if the restricted model is better than the enriched one by checking if the ratio is significantly different from zero.

3.3. Lisbon case study

Humberto Delgado Airport is also known by Portela Lisbon Airport and it is only 7km away from the Lisbon city centre, the capital of Portugal (Figure 3.2). Inaugurated on the 15th of October 1942, it has 2 civil terminals (T1 and T2 for LCC departures) and one military terminal known as Figo Maduro Airport. The airport is the main hub of the Portuguese front-carrier TAP Air Portugal and is run by ANA Aeroportos de Portugal, S.A. In 2013, the ANA operating company integrated the French group VINCI Airports.

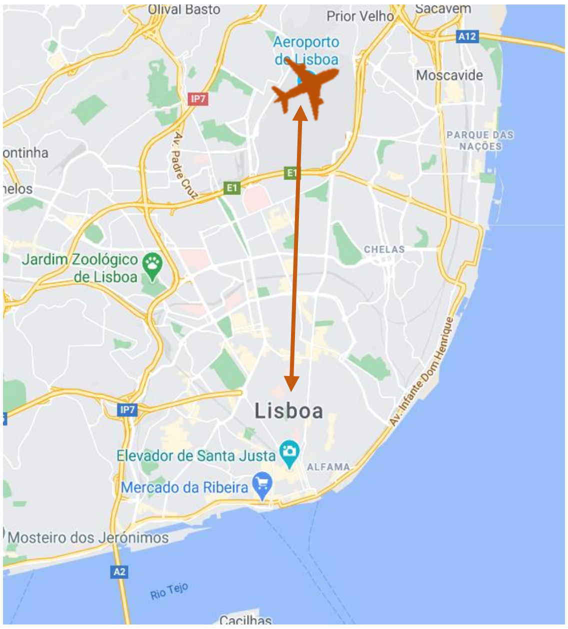

Figure 3.2 – Location of the Lisbon Airport.

According to ANA Aeroportos de Portugal Annual Report (2019), Lisbon Airport is the most crowded airport in Portugal, being responsible for more than 50% of the entire country airport passengers (around 59.1 million). In 2019, it served a total of 31.1 million commercial passengers, an increase of 7.4% compared to 2018, and accounted for 217.7 thousand aircraft movements which represents an increase of 1.9%. The largest increases in passenger numbers were recorded in the following origin/destination pairs: Spain (plus 795 thousand), UK (plus 718 thousand), Italy (plus 284 thousand), Brazil (plus 270 thousand) and France (plus 254 thousand).

As expected, the aviation business sector in 2019 represented 73.2% of total ANA Group revenue, meaning 657.3 million euros. The remaining 26.8% revenues are accounted by the non-aviation business sector which amounted to 241.2 million euros, a one-year increase of 10.1%. The rent-a-car and car parking businesses are responsible for 15.9% and 12,6%, respectively, of the non-aviation income (Figure 3.3). The numbers reveal that both businesses continued to grow, with a rise of 15.8% (rent-a-car) and 3.6% (car parking) over the previous year. The increase in the car parking revenue stream is a result of several initiatives implemented over 2019 aimed at improving the quality of the service, such as: an overhaul online booking platform, allowing passengers to get the best rates and secure their parking space; a consolidation of the application of the recent Kiss & Fly parks (i.e. parking areas specially reserved for quick and free of charge stops, up to ten minutes); a greater curbside control and management systems at Lisbon and Porto airports which are often congested areas, among others (ANA Aeroportos de Portugal Annual Report, 2019).

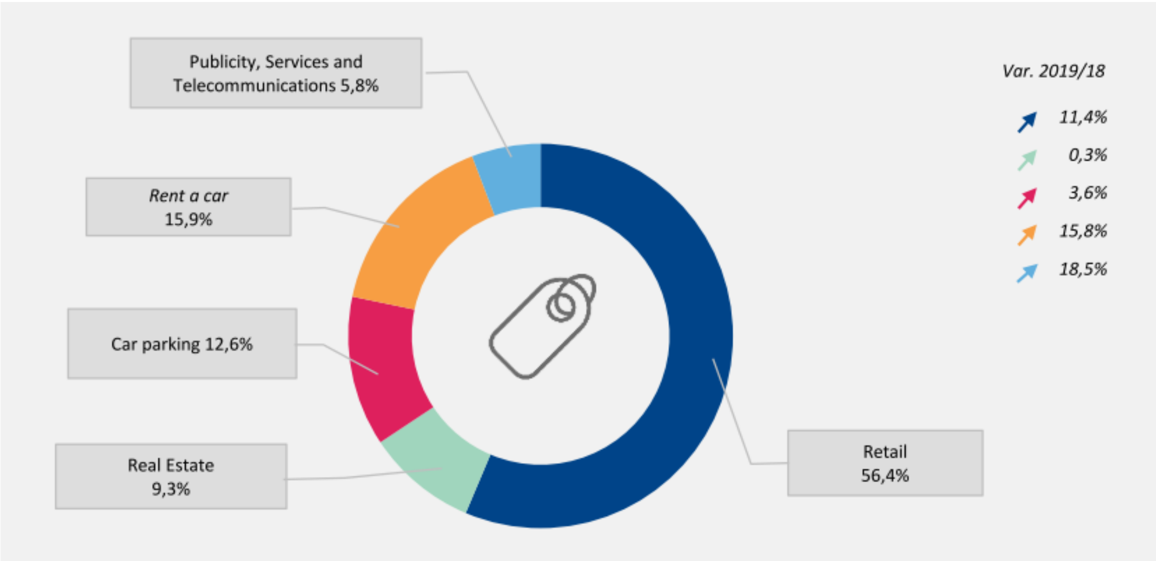

Figure 3.3 – Distribution of ANA Group's non-aviation business (Source: *ANA Aeroportos de Portugal Annual Report*, 2019)

At present, a passenger has many options to access or egress the Lisbon Airport. Its close location to the city centre allows for a diverse network of private and public transports that can ensure an easy and comfortable trip in just 20 minutes. However, the widespread road congestion generally compromises the airport's ability to offer pleasant trips and reliable travel times. Overall, the possible alternative private and public transport modes for Lisbon Airport ground access are the following (Portugal ANA, 2016):

- **Underground metro (subway)**: the "Aeroporto – Saldanha" line takes a passenger directly to the city centre in a quick and inexpensive way.

- **Bus:** there are several bus lines stop at the airport arrivals terminal, however there is a maximum baggage size limit.
- **Aerobus:** if a passenger baggage exceeds the above-mentioned size limit, one must take the airport's specific bus. With departures every 30 min, there are two different bus routes providing a link between the main city points and the airport. One of them provides a direct link from the airport to Sete Rios train station, with no stops, and vice-versa.
- **Train**: the main train station in Lisbon, *Gare do Oriente*, is only 10 minutes away by Metro and a bit longer by bus, where is possible to take trains to all parts of the country.
- **Taxi:** there are normally many taxis queueing outside the departures and arrivals terminals
- **Private vehicle:** Terminal 1 has several parking options whereas Terminal 2 has none. Once parked at Terminal 1, the passenger can take the free shuttle to Terminal 2.
- **Rental car:** the passenger has at his disposal several rent-a-car companies, such as Avis-Budget, Europcar, Goldcar, Guerin, Hertz and Sixt.
- **Emov:** the airport offers a shared use service of vehicles with rates by the minute.
- **Ride-hailing providers:** in addition to the most well-known companies like Uber, Bolt, Free Now, etc., there are many other offering the same services in Lisbon.

3.3.1. Data treatment

In the released survey, each respondent is observed to choose one (or more if multimodal) alternative mentioned above. Nevertheless, the mode choice dataset included three alternatives: car, ride-hailing and public transport. The car alternative represents private vehicle, rental car, Emov and being picked-up/dropped-off options, whereas the ride-hailing one comprises the car-sharing, taxi, hotel transfer and the ride-hailing services such as Uber, as suggested by the name. For the scope of this study, it would be appropriate to detach taxi and services like Uber, but there were not enough taxi observations (37) and these two options had to be considered together. At last, the public transport alternative contains the bus, metro, train and Aerobus options.

Travel time and cost were calculated for each origin-destination ground trip pair by using a script in Rome2Rio application. Below is presented an example of the information obtained for the Belém-Airport ground trip pair.

Table 3.1 – Example of the information obtained for the Belém-Airport ground trip pair using the script in Rome2Rio application.

Transport mode	Travel Time	Travel Cost
Subway	29 min	2€
Bus + subway	43 min	2€ - 4€
Bus	45 min	2€ - 5€
Taxi	10 min	10€ - 13€
Drive	10 min	1€ - 2€

The travel time and cost considered for the public transport alternative were then chosen based on the author's fair judgement within the various options obtained. It is worth of mention that each ride-hailing final cost was given by the average between the taxi and Uber's value since taxi's values are a bit more expensive. The Uber's values were obtained by the respondents' data or directly from the Uber application for those origin-destination pair with no data. Moreover, the total cost considered for the car alternative is the sum of the fuel cost obtained from the application and the cost of parking given by the respondents' data. Finally, it is observed that the travel times for the ride-hailing option are the same as for the car mode.

4. Access Mode Choice Modelling in Lisbon Airport

This chapter presents the survey sample and statistical results of passengers departing from and arriving at Lisbon Airport. Then, the estimated discrete choice models are presented and explained. Last, the main results are discussed and compared with literature.

4.1. Survey statistics

The total number of valid answers collected with this survey was 474. However, only 319 were considered since data sample aimed to represent the general passengers of Lisbon Airport living or visiting the Metropolitan Area of Lisbon as close as possible. Therefore, the remaining observations (155) where the destination (origin) of the respondent's trip (up to) from the airport was outside this area were excluded from the dataset. Moreover, besides the author’s limited time and effort, the sudden appearance of coronavirus and resulting abrupt drop in world air traffic made it difficult to gather a higher number of answers. On the other hand, it is expected to have a low percentage of older people and foreigners, since this survey was mainly shared with the author’s network. Despite all this, the 319 answers seem a reasonable number for this dissertation, since it is supposed to represent a very specific nest of the society.

Figure 4.1 indicates that 96.2% of the passengers are Portuguese and that 98.1% live in Portugal. In addition, it shows that the data sample is almost evenly divided between men (50.5%) and women (49.5%). Finally, there were more respondents from young people (29.5%), specifically between the ages of 18 and 24 years old, whereas only 1.6% of the registered answers belong to passengers over 64 years old. The remaining passengers are distributed among the other age groups, with similar percentages (13.5% - 20.4%).

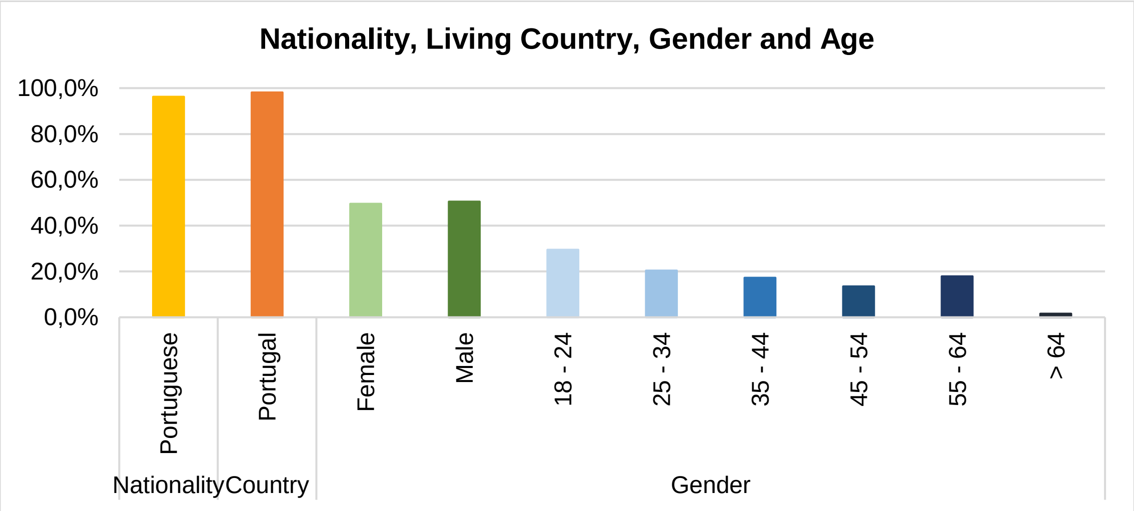

Figure 4.1 - Passengers’ socioeconomic characteristics: nationality (only the Portuguese is represented), living country (only Portugal is represented), gender and age.

The occupation and net income of the passengers are represented by Figure 4.2. Most of the passengers have a full-time work (59.2%) and 23.8% are students. Moreover, almost half of the passengers have a net income between 1000€ and 2999€ (54.3%) and only a few portion of the passengers gain more than 4999€ (5%) or less than 500€ (3.8%) per month. The remaining percentages of both the occupation and net income graphs correspond to the respondents that preferred not to answer to the questions.

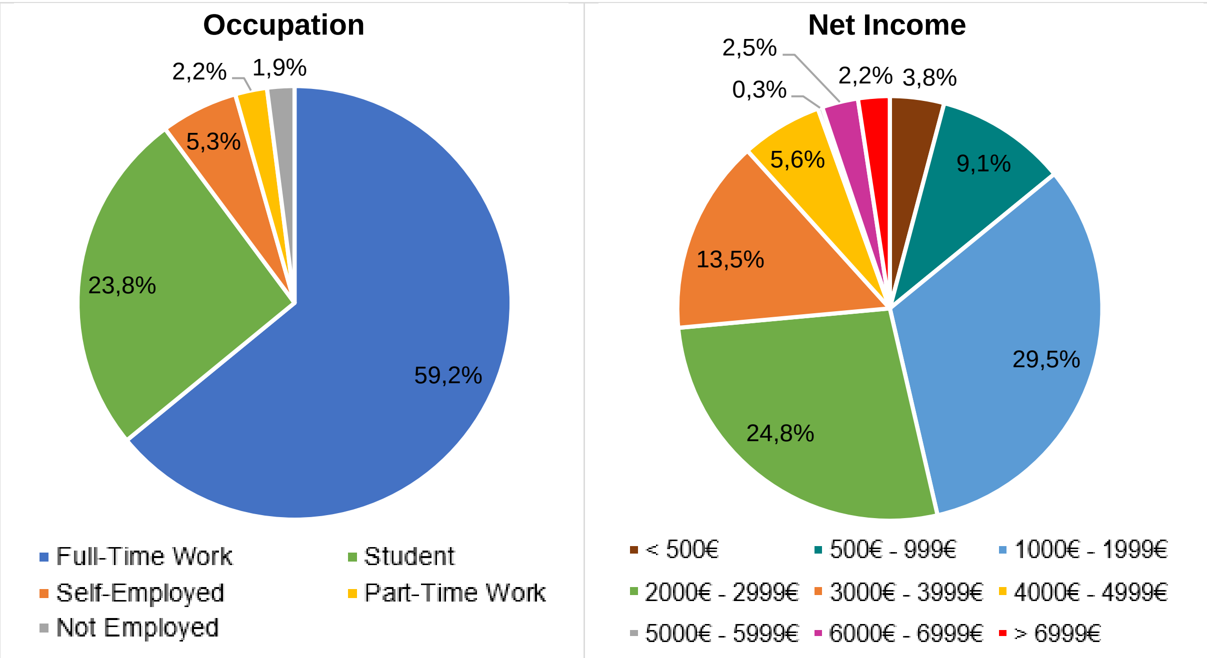

Figure 4.2 – Passengers' socioeconomic characteristics: left – occupation; right - net income.

As it can be observed by Figure 4.3, 91.9% of the respondents have a driving license. In addition, this graph confirms that almost half of the passengers own a private vehicle (45.8%). Furthermore, it also represents the percentage of people with two vehicles (27.3%), three or more vehicles (7.5%) and those who do not own any vehicles (19.4%).

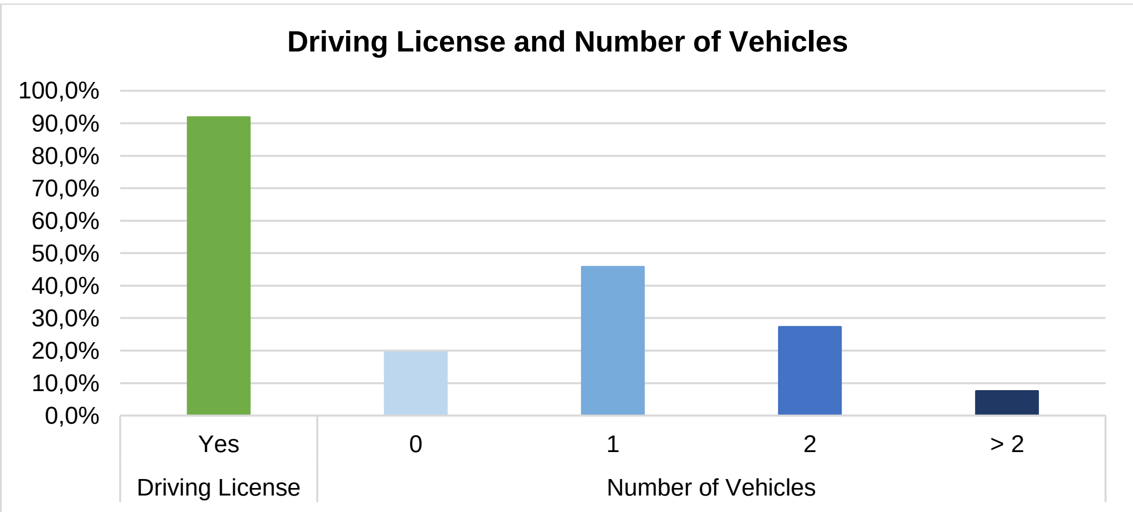

Figure 4.3 – Passengers' socioeconomic characteristics: representation of people with driving license and number of vehicles.

The information regarding the number of air trips (one trip being one departure and arrival) that the respondents do per year, in total and using Lisbon Airport, is present in Figure 4.4. Most of the passengers travel less than 4 times a year (75.6%) and use the airport also less than 4 times a year (77.7%). Similarly, about a fifth of the people travel (21.3%) and use Lisbon Airport (20.1%) between 4 to 12 times a year. Finally, only 3.1% of the passengers have more than 12 trips per year and 2.2% resort to Lisbon Airport.

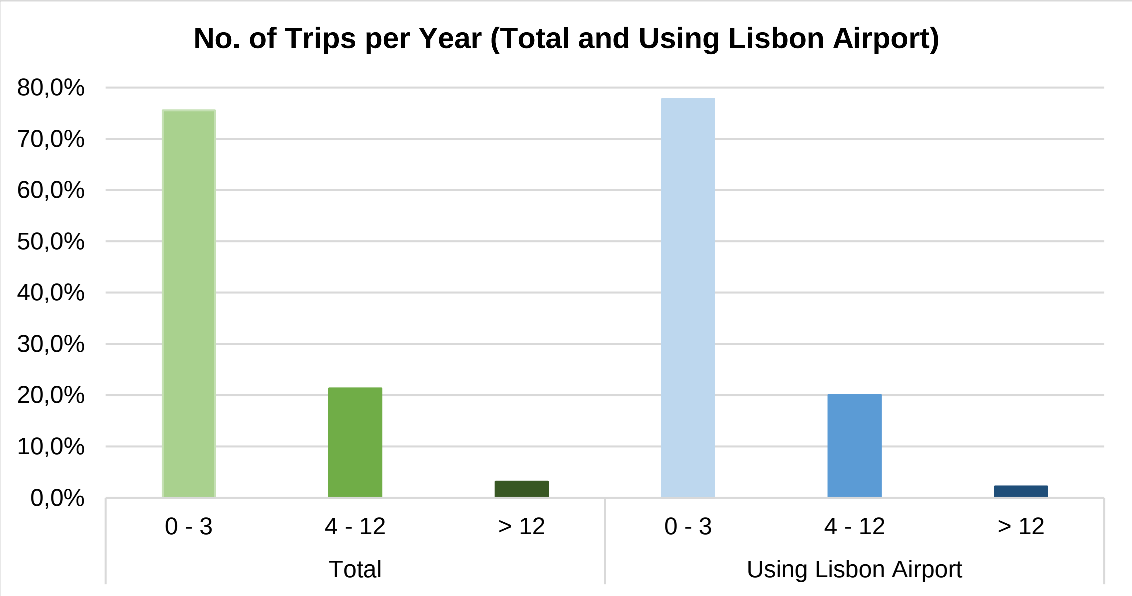

Figure 4.4 – Passengers' socioeconomic characteristics: number of trips per year in total and using Lisbon Airport.

Figure 4.5 represents the distance from the respondents' residence to the closest public transportation station and the daily transportation mode they use to go to work.

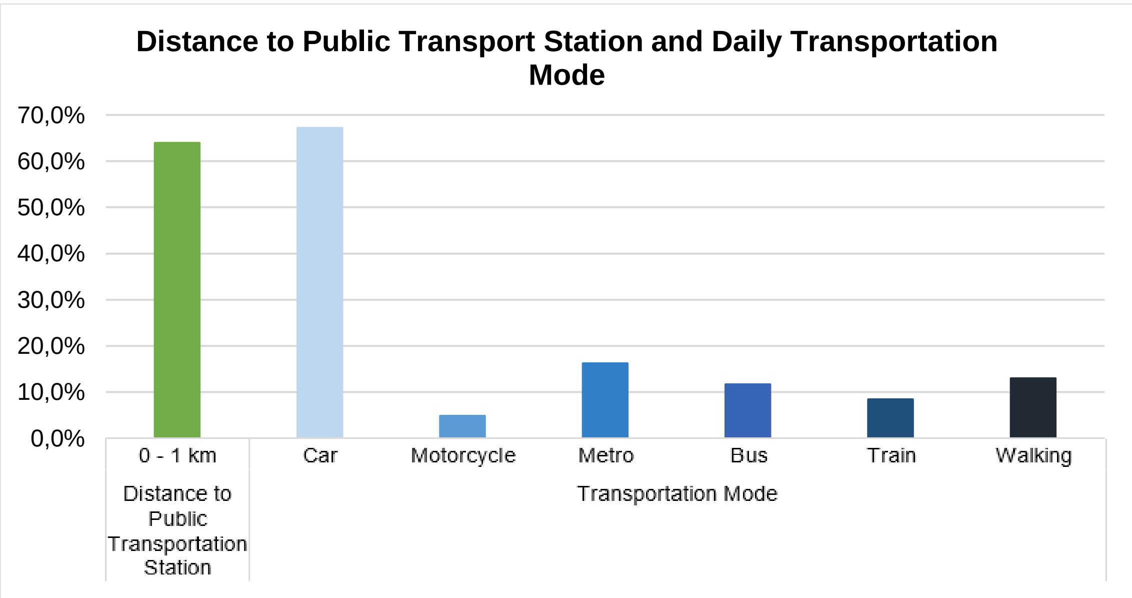

Figure 4.5 - Passengers' socioeconomic characteristics: distance between their residence and the closest public transport station and basic transportation mode to work in their home city.

As it can be seen, 64% of the respondents live less than 1 km away from the closest public transport station. Additionally, Figure 4.5 also shows that most people use their car to get to work (67.2%) and that 16.2% take the metro. Furthermore, 13% of the people walk to go to work, 11.7% take the bus and 8.4% use the train. Finally, a minority uses a motorcycle to move around (4.9%). Note that some respondents have selected more than one option, which means that some of them combine many transportation modes to go to work.

Moving on to the characteristics of the trip, Figure 4.6 represents the transportation alternative chosen by the passengers to get to or from Lisbon Airport. Most of the respondents chose to be picked-up or dropped-off by a family member, friend, colleague, or someone else (31.4%) and a fifth (20.7%) preferred to use a ride-hailing option, representing the second most chosen alternative. About 18.2% of the people used their private vehicle, whereas 2.8% resorted to a rental one, and 11.6% preferred to take a taxi to go to or from the airport. The most chosen public transportation mode was the metro, accounting for 10.34% of all responses, and the remaining two options represent about 2-3% (bus – 1.9%; train – 2.8%). Both Emov and Aerobus were the least chosen alternatives, with a percentage of 0.31% and 0%, respectively.

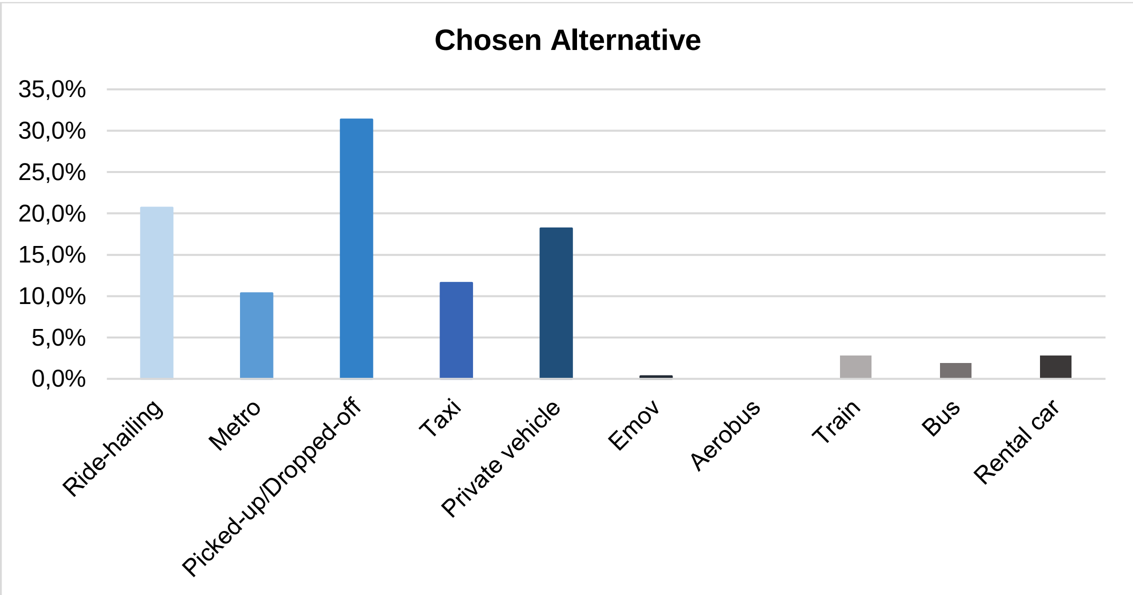

Figure 4.6 - Trip characteristics: type of transportation alternative chosen to get to/from the airport.

When people were asked if they would use the same transportation alternative again, 96.6% of them answered positively, as represented in Figure 4.7. In addition, this graph offers information about the level of knowledge on all the available alternatives to access or leave the airport. As can be noted, most of the people know very well all the options (5 - 32.9%) and only 6.3% (1) have no idea which are the available alternatives.

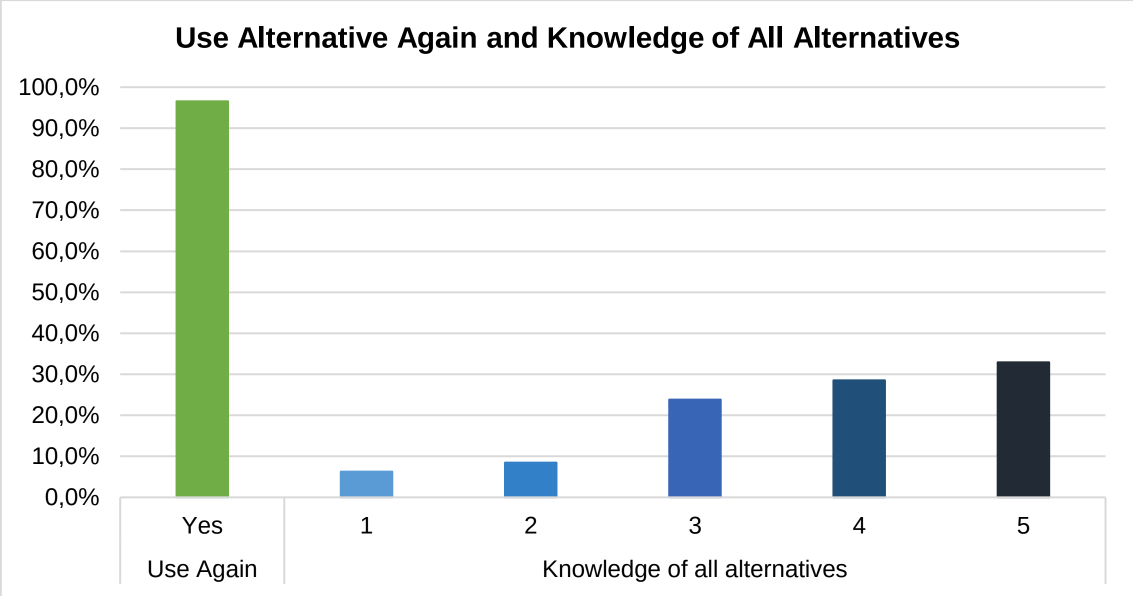

Figure 4.7 – Trip characteristics: representation of people that would use the same transportation again and knowledge of all the available transportation alternatives (rated from 1 - no idea - to 5 - very well).

In Figure 4.8 is present the type of flight taken by the passengers. The results show that 57.7% of the people arrived at Lisbon Airport (inbound) and the remaining 42.3% represent the departure flights (outbound). The trip purpose is also represented by Figure 4.8, which indicates that most people went on a leisure trip (54.3%). In addition, about 23.5% were business trips and 12.9% of them were paid by the company. Finally, the purpose of 19.8% of all trips was to visit relatives or friends.

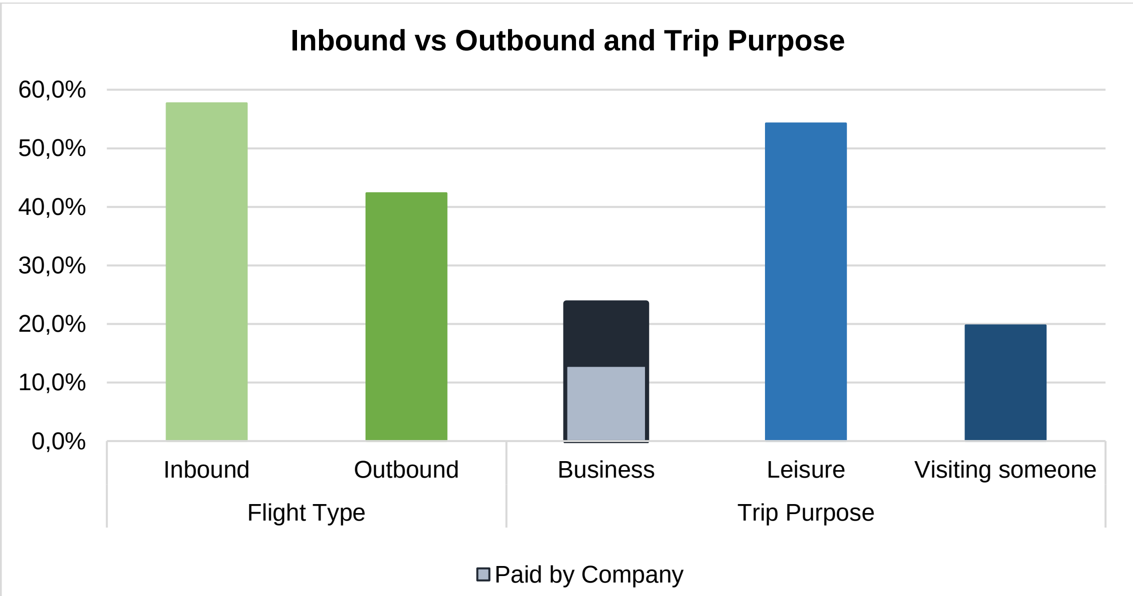

Figure 4.8 – Trip characteristics: type of flight (inbound or outbound) and trip purpose (in the business case, it is also included the percentage of people whose trip was paid by the company).

Figure 4.9 concerns the characteristics of the flight, i.e., whether it was a low-cost, long haul and/or domestic flight. The results show that 35.7% of the passengers took a low-cost flight, 24.5% of all flights were domestic and that only 9.7% were long haul. Additionally, Figure 4.9 also reveals that 38.6% of the passengers were away from their residence for 7 days or more.

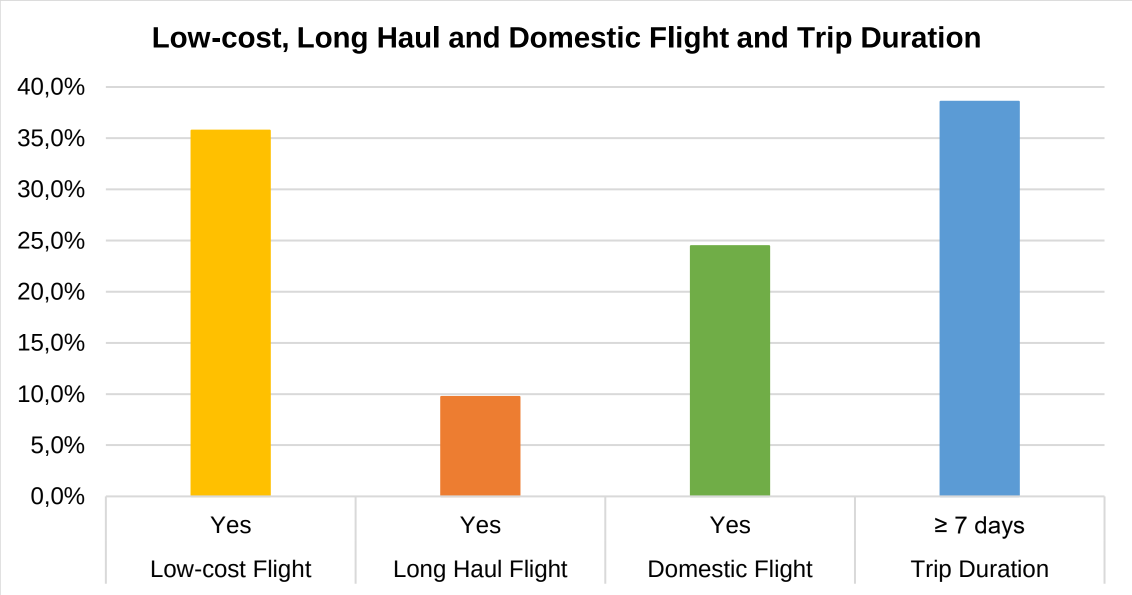

Figure 4.9 – Trip characteristics: representation of people whose flight was low-cost, long haul and/or domestic and those who were 7 or more days away from their residence.

Next, some of the flight services that the passengers chose, whether they made purchases at Lisbon Airport and the type of check-in the outbound passengers chose are described in Figure 4.10.

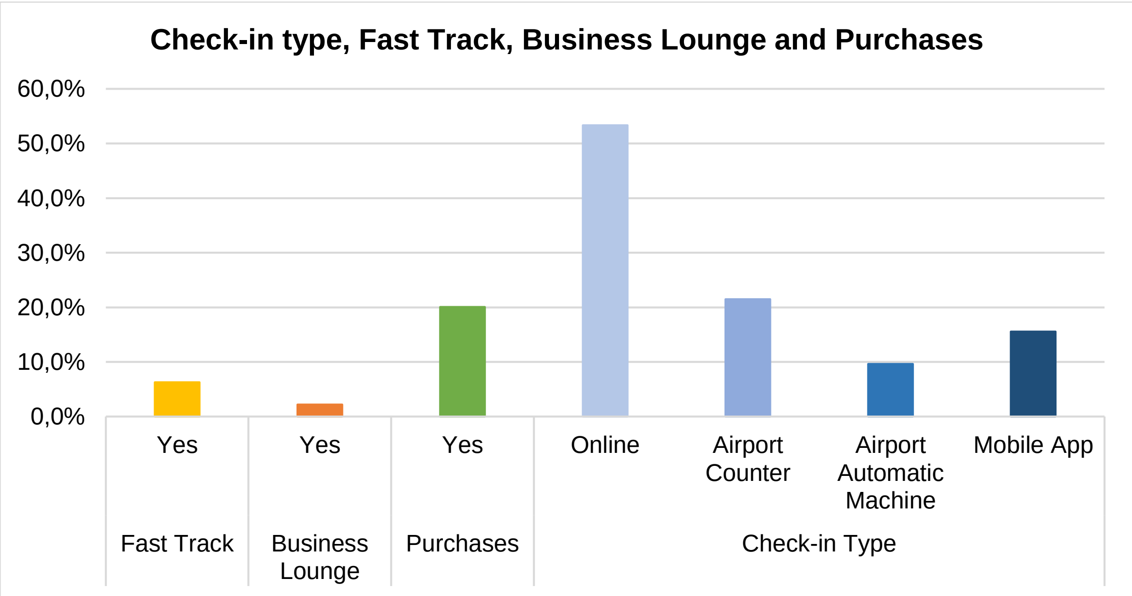

Figure 4.10 - Trip characteristics: representation of people who used fast track, business lounge and made purchases at the airport and type of check-in.

About 6.3% of the passengers selected the fast track option and only 2.2% preferred to benefit from the business lounge available at the airport. Furthermore, purchases at the airport were made by 20.1% of the passengers. Regarding the available alternatives to check-in, more than half of the people chose to do it online (53.3%) and 21.5% used an airport counter for that purpose. The two remaining options, which concern the use of a mobile application or an automatic machine at the airport, were selected by 15.6% and 9.6% of the people, respectively.

Figure 4.11 represents the number of bags throughout the trip: the ones that the passengers had to check-in at the departing airport, the ones the passengers had on the plane and the ones that had to be collect at the baggage claim area. Regarding the baggage to check-in, the percentage of the respondents decreases as the number of bags increases, going from 68.4% to 0.31%. The same behaviour is observed for the baggage to claim at the destination airport, with similar percentages (68.2% to 0.63%). Moreover, most people only had one bag on the plane (79.9%) and 12.5% had two pieces of baggage. About 6% of the passengers did not take any baggage with them and less than 2% had three or more bags on the plane (3 – 0.63%; more than 3 – 0.94%).

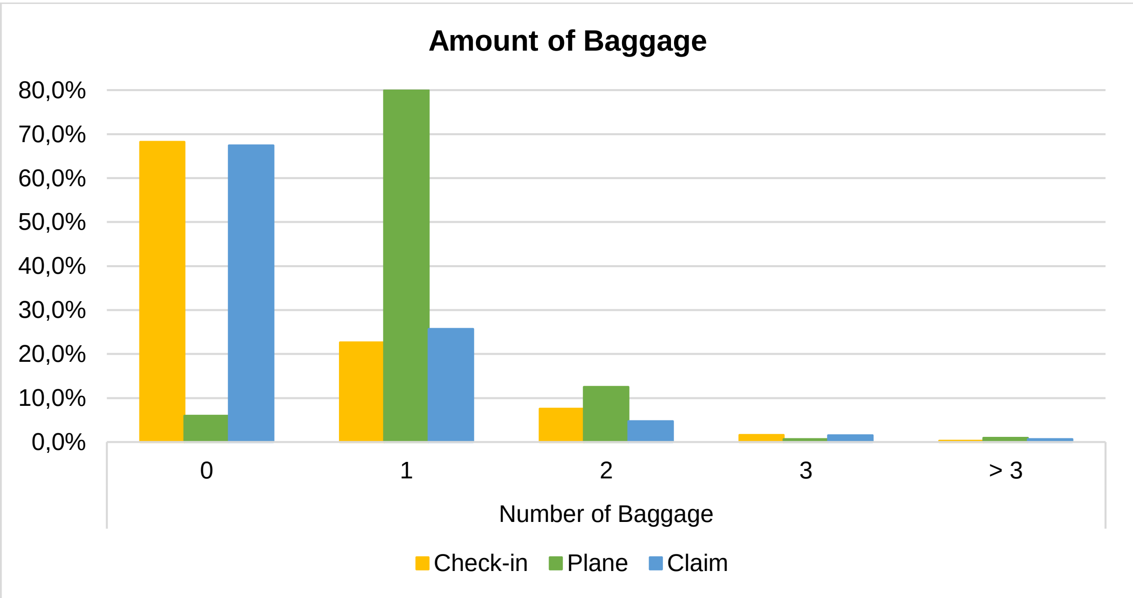

Figure 4.11 – Trip characteristics: number of bags to check-in, to have in the plane and to collect at the baggage claim area.

Regarding the party size question, to those who answered one or more people, it was also asked how many of them were children. This information is present in Figure 4.12. and, as it can be noted, 38.2% travelled with one person and 28.2% travelled alone, which represents about 66.4% of all the respondents. Regarding the remaining passengers, 14.1% travelled with two people, 9.1% with three, 4.4% with four and 6% with more than four. Additionally, most of the accompanying passengers were not children (84.3%) and 8.5% of the respondents travelled with one child. Finally, less than 4% of the passengers had two or three children with them (2 – 3%; 3 - 0.9%).

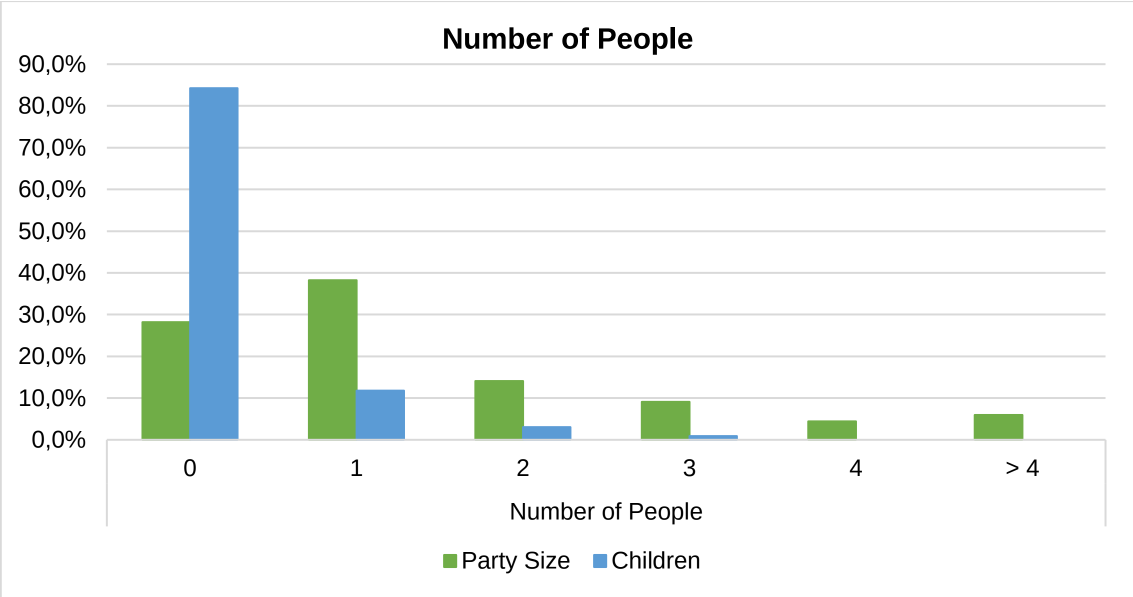

Figure 4.12 - Trip characteristics: number of people the passengers travel with and how many of them were children.

Finally, the last graph concerns the raining conditions on the trip day and the period of the day the trip took place. The results in Figure 4.13 show that only 8.2% of the trips occurred in a rainy day and that most of the trips took place in the morning (46.1%). Additionally, there were 28.2% afternoon flights and 17.9% night flights. The remaining passengers did not remember this information.

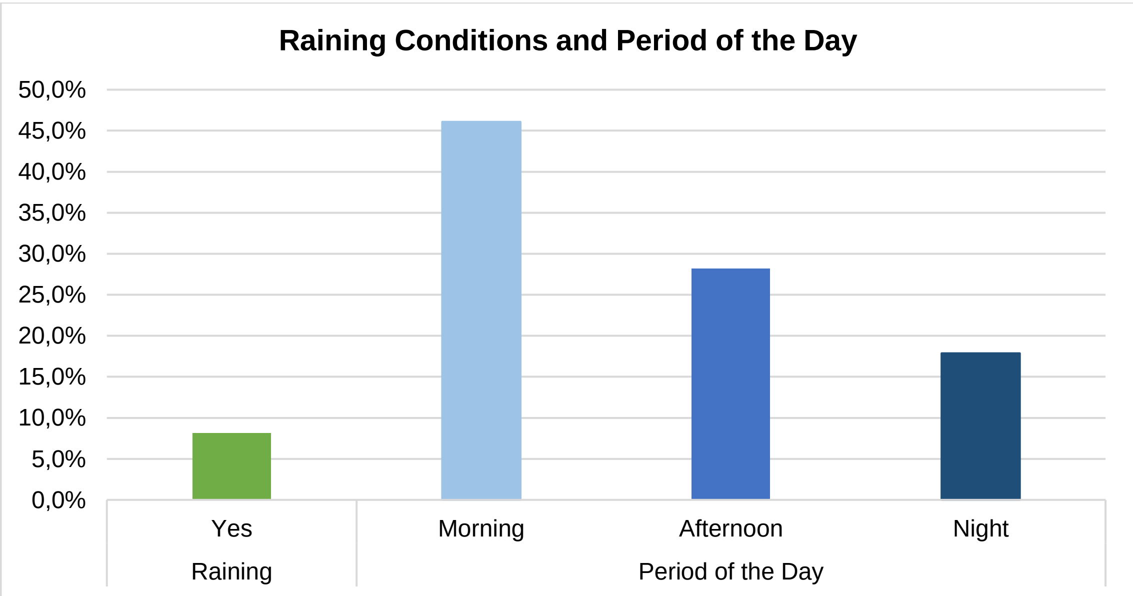

Figure 4.13 – Trip characteristics: weather conditions (if it was raining on the day of the trip) and period of the day the trip took place.

4.2. Multinomial logit mode choice models

4.2.1. Choice set with three alternatives

Model 1: Common cost and time effect on alternatives

By using Biogeme software (Bierlaire, 2003), several specification tests were conducted to identify which characteristics are more relevant for the passengers' mode choice to access the Lisbon Airport. As previously mentioned, three alternatives were considered: car (Car), ride-hailing ($RideH$) and public transport (PuT). In order to capture the unknown factors, an alternative-specific constant (ASC) was added in each utility form.

At first, it was tested equal coefficients for travel cost and time variables to capture their common effect in each alternative's utility function. The final estimation results of the MNL are presented in Table 4.1 and Table 4.2 The resulting utility functions and the respective tested variables are the following:

$$V_{Car} = ASC_{car} + \beta_{cost} \cdot cost_{Car} + \beta_{TT} \cdot TT_{CarRideH}$$

$$V_{PuT} = ASC_{PuT} + \beta_{cost} \cdot cost_{PuT} + \beta_{TT} \cdot TT_{PuT}$$

$$V_{RideH} = ASC_{RideH} + \beta_{cost} \cdot cost_{RideH} + \beta_{TT} \cdot TT_{CarRideH}$$

Table 4.1 - Estimated parameters values with three alternatives and common cost and time effect.

Parameter name	Variable description	Parameter value	t-statistic
$\boldsymbol{ASC_{Car}}$	-	0.00	-
$\boldsymbol{ASC_{PuT}}$	-	-1.35	-2.99
$\boldsymbol{ASC_{RideH}}$	-	0.521	1.86
$\boldsymbol{\beta_{TT}}$	Continuous variable for travel time in V_{Car}, V_{PuT} and V_{RideH}	-0.0222	-1.44
$\boldsymbol{\beta_{cost}}$	Continuous variable for travel cost in V_{Car}, V_{PuT} and V_{RideH}	-0.0804	-4.23*

*Significant at the 5% level

Table 4.2 - Validation results with three alternatives and common cost and time effect.

Number of observations	260
Number of estimated parameters	4
Null log-likelihood ($\boldsymbol{L(0)}$)	-285.639
Log-likelihood ($\boldsymbol{L(\beta)}$)	-213.669
Likelihood ratio test	143.940

Travel time was found to be non-significant as presented in Table 4.1. On the other hand, the expected negative effect of the journey cost for any of the three alternatives is illustrated by the common β_{cost} with negative sign.

Model 2: Alternative-specific parameters for travel cost and time used as continuous variables

After analysing the common travel time and cost effect on the three different alternatives, it is important to test these variables' alternative-specific parameters. The final estimation results are presented in Table 4.3 and Table 4.4 and the resulting utility functions are given by:

$$V_{Car} = ASC_{car} + \beta_{cost_{Car}} \cdot cost_{Car} + \beta_{TT_{Car}} \cdot TT_{CarRideH}$$

$$V_{PuT} = ASC_{PuT} + \beta_{cost_{PuT}} \cdot cost_{PuT} + \beta_{TT_{PuT}} \cdot TT_{PuT}$$

$$V_{RideH} = ASC_{RideH} + \beta_{cost_R} \cdot cost_{RideH} + \beta_{TT_R} \cdot TT_{CarRideH}$$

Table 4.3 - Estimated parameters values with three alternatives and alternative-specific parameters for travel cost and time used as continuous variables.

Parameter name	Variable description	Parameter value	t-statistic
ASC_{Car}	-	0.00	-
ASC_{PuT}	-	-0.858	0.16
ASC_{RideH}	-	1.08	0.00
$\beta_{TT_{Car}}$	Continuous variable for travel time in V_{Car}	0.0640	0.48
$\beta_{TT_{PuT}}$	Continuous variable for travel time in V_{PuT}	0.0162	0.48
β_{TT_R}	Continuous variable for travel time in V_{RideH}	0.0376	0.72
$\beta_{cost_{Car}}$	Continuous variable for travel cost in V_{Car}	-0.00579	0.66
$\beta_{cost_{PuT}}$	Continuous variable for travel cost in V_{PuT}	-0.239	0.49
β_{cost_R}	Continuous variable for travel cost in V_{RideH}	-0.0848	0.03*

*Significant at the 5% level

Table 4.4 - Validation results with three alternatives and alternative-specific parameters for travel cost and time used as continuous variables.

Number of observations	260
Number of estimated parameters	8
Null log-likelihood ($L(0)$)	-285.639
Log-likelihood ($L(\beta)$)	-204.723
Likelihood ratio test	161.832

As presented in Table 4.3, only the cost of the ride-hailing alternative was found to be an explanatory variable ($cost_{RideH}$).

Model 3: Alternative-specific parameters for alternative attributes, trip and passenger characteristics

Besides the alternative-specific parameters, it should be also tested several trip and passenger characteristics. In this case, the specification of car alternative is only composed by the ASC and the deterministic utility is fixed to zero. The equivalent ASC and several parameters related to the expected relevant variables were used in the utility form of the other two alternatives. The resulting utility functions and the respective variables that explain the passenger mode choice are the following:

$$V_{Car} = ASC_{car}$$

$$V_{PuT} = ASC_{PuT} + \beta_{cost_{PuT}} \cdot cost_{PuT} + \beta_{Many\_Days} \cdot Many\_Days$$

$$V_{RideH} = ASC_{RideH} + \beta_{cost_R} \cdot cost_{RideH} + \beta_{Long\_Haul} \cdot Long\_Haul + \beta_{GroupOf4} \cdot GroupOf4 + \beta_{1Child} \cdot Children1$$

The final estimation results of the MNL are presented in Table 4.5 and Table 4.6. All variables are significant at the 5% or 10% level and there was no evidence of significant correlations among them, meaning that they are fairly independent. The analysis of the parameters' values is presented below:

- $\boldsymbol{\beta_{cost_{PuT}}}$: the cost of the journey for the public transport choice ($cost_{PuT}$) has a negative effect, implying that if the cost increases, the probability of choosing this mode decreases
- $\boldsymbol{\beta_{cost_R}}$: a similar analysis to the one above can be deduced for the journey cost of the ride-hailing choice ($cost_R$)
- $\boldsymbol{\beta_{Many\_Days}}$: if the duration of the trip was longer than seven days ($Many\_Days$), it is likely that the individual will travel with more luggage and therefore less expected to use the public transport. The negative sign of the coefficient is according to this assumption
- $\boldsymbol{\beta_{Long\_Haul}}$: the positive coefficient for long-distance flights ($Long\_Haul$) in the ride-hailing function can be explained by the fact that passengers avoid driving and prefer to take a taxi or Uber to alleviate the fatigue of the long journey they have just made or are about to make
- $\boldsymbol{\beta_{GroupOf4}}$: for a family or a group of five, rental cars or driving and parking at the airport are more attractive options, which explains the negative sign of the $GroupOf4$ coefficient in the ride-hailing function
- $\boldsymbol{\beta_{1Child}}$: even if it is not such a straightforward assumption, the positive effect of $Children1$ variable (i.e., travelling with one child) in the ride-hailing utility may be

explained by the fact that children are usually accompanied by their mother, who are more likely to favour taxi mode over driving as previously mentioned in the literature.

Table 4.5 – Estimated parameters values with three alternatives and alternative-specific parameters for alternative attributes, trip and passenger characteristics.

Parameter name	Variable description	Parameter value	t-statistic
ASC_{car}	-	0.00	-
ASC_{PuT}	-	-0.273	-0.50
ASC_{RideH}	-	1.02	3.87
β_{1Child}	1 if passenger travels with one child in V_{RideH}	1.23	2.48*
$\beta_{GroupOf4}$	1 if passenger travels with 4 more people in V_{RideH}	-2.43	-2.86*
β_{Long_Haul}	1 if passenger takes a long-haul flight in V_{RideH}	1.18	2.48*
β_{Many_Days}	1 if the trip duration is longer than 7 days in V_{PuT}	-1.09	-1.93**
$\beta_{cost_{PuT}}$	Continuous variable for travel cost in V_{PuT}	-0.348	-2.53*
β_{cost_R}	Continuous variable for travel cost in V_{RideH}	-0.111	-6.56*

*Significant at the 5% level
**Significant at the 10% level

Table 4.6 – Validation results with three alternatives and alternative-specific parameters for alternative attributes, trip and passenger characteristics.

Number of observations	260
Number of estimated parameters	8
Null log-likelihood $(\boldsymbol{L}(\mathbf{0}))$	-285.639
Log-likelihood $(\boldsymbol{L}(\boldsymbol{\beta}))$	-195.826
Likelihood ratio test	179.626
Percentage of choice probabilities: > 50%	25%

Several other variables were tested but proved to be non-significant as present in Table 4.7.

Table 4.7 – Examples of the non-significant coefficients tested with three alternatives and alternative-specific parameters for alternative attributes, trip and passenger characteristics.

Parameter name	Variable description	Parameter value	t-statistic	p-value
ASC_{car}	-	0.00	-	-
ASC_{PuT}	-	-0.981	-0.83	0.41
ASC_{RideH}	-	1.36	3.52	0.00
$\beta_{18to24P}$	1 if passenger is between 18 to 24 years old in V_{PuT}	-0.0738	-0.14	0.89
$\beta_{18to24R}$	1 if passenger is between 18 to 24 years old in V_{RideH}	0.262	0.71	0.48
β_{1Child}	1 if passenger travels with one child in V_{RideH}	1.27	2.53	0.01
β_{Check_0Bag}	1 if passenger does not check-in any bag in V_{PuT}	0.262	0.37	0.71
$\beta_{GroupOf4}$	1 if passenger travels with 4 more people in V_{RideH}	-2.32	-2.72	0.01
β_{Km_PuT}	1 if passenger lives less than 1km from closest public transport station in V_{PuT}	-0.256	-0.47	0.64
β_{L500}	1 if passenger's net income is less than 500€ in V_{PuT}	1.06	0.76	0.45
β_{LCC}	1 if passenger takes a low-cost flight in V_{PuT}	0.0894	0.13	0.89
β_{Long_Haul}	1 if passenger takes a long-haul flight in V_{RideH}	1.21	2.55	0.01
β_{Many_Days}	1 if the trip duration is longer than 7 days in V_{PuT}	-1.23	-1.96	0.05
β_{Night}	1 if passenger takes a night flight in V_{PuT}	0.587	0.82	0.41
$\beta_{NoGroup}$	1 if passenger travels alone in V_{PuT}	0.146	0.25	0.80
$\beta_{NoVehicles}$	1 if passenger does not own any vehicle in V_{PuT}	0.452	0.70	0.48
β_{Plane_1Bag}	1 if passenger takes one bag in the plane in V_{PuT}	0.00824	0.01	0.99
$\beta_{Raining}$	1 if rains on the trip's day in V_{PuT}	1.36	1.78	0.07
$\beta_{TT_{Car}}$	Continuous variable for travel time in V_{Car}	0.0515	0.56	0.57
$\beta_{TT_{PuT}}$	Continuous variable for travel time in V_{PuT}	0.0207	0.78	0.43
β_{TT_R}	Continuous variable for travel time in V_{RideH}	0.0246	0.24	0.81
β_{busi_tripP}	1 if passenger takes a business trip in V_{PuT}	0.03	0.04	0.97
β_{busi_tripR}	1 if passenger takes a business trip in V_{RideH}	-0.389	-1.03	0.30
$\beta_{cost_{Car}}$	Continuous variable for travel cost in V_{Car}	-0.00503	-0.40	0.69
$\beta_{cost_{PuT}}$	Continuous variable for travel cost in V_{PuT}	-0.320	-0.87	0.38
β_{cost_R}	Continuous variable for travel cost in V_{RideH}	-0.0942	-2.55	0.01
β_{gender}	1 if the passenger is a woman in V_{RideH}	-0.574	-1.75	0.08

It is worth noting that although the cost of the public transport variable revealed to be significant when tested at first, it turned out to be non-explanatory with the use of several other non-significant variables. Consequently, the above MNL model has been tested again but without considering this variable. The estimation results of this model are presented in Table A.2 and A.3 in Appendix A.2.

The MNL model was estimated with around 80% of the dataset (260 observations) and the remaining 20% (59 observations) were reserved for validation of accuracy of the model. This validation is based on the match percentage of the 59 estimated choices with the use of the previously estimated choice probabilities. Based on this validation, 25% of the 59 observations were correctly estimated by the model with a probability higher than 50%. It is an expected result due to the lower number of observations with the chosen public transport option that make its explanation more difficult.

Model 4: Alternative-specific parameters for travel cost and time used as categorical variables

In the previous models, the estimated parameters remained constant throughout the whole range of the values of travel cost and time variables. However, only the cost of the ride-hailing alternative was proved to be an explanatory variable and was included in the respective utility function. According to Ben-Akiva and Lerman (1985), assuming different ranges of values for some variables may be more justified in some cases. Therefore, the related cost parameters for the car and public transport alternatives were split in different intervals as well as those of the travel time for the three alternatives. The intervals were defined based on the histograms of the various variables and are listed Table 4.8.

After testing all the above intervals, only the parameter $\beta_{TT_{Car1}}$ of $TT_{CarRideH1} \in (0{,}10)$ in the car alternative utility function was found to be significant at 5% level. When considered all the intervals, the software was not able to estimate the model since there was not variance between data ($p = 1$) and thereby total estimation results are not reliable.

Table 4.8 – Travel cost and time categories.

Variable	Range of Values
$\boldsymbol{cost_{Car1}}$	$[0,5)$
$\boldsymbol{cost_{Car2}}$	$[5,10)$
$\boldsymbol{cost_{Car3}}$	$[10,+\infty)$
$\boldsymbol{Fuel\_cost1}$	$[0,1)$
$\boldsymbol{Fuel\_cost2}$	$[1,4)$
$\boldsymbol{Fuel\_cost3}$	$[4,+\infty)$
$\boldsymbol{Park\_Charges1}$	$[0,5)$
$\boldsymbol{Park\_Charges2}$	$[5,+\infty)$
$\boldsymbol{cost_{PuT1}}$	$[0,3)$
$\boldsymbol{cost_{PuT2}}$	$[3,6)$
$\boldsymbol{cost_{PuT3}}$	$[6,+\infty)$
$\boldsymbol{TT_{PuT1}}$	$[0,12)$
$\boldsymbol{TT_{PuT2}}$	$[12,22)$
$\boldsymbol{TT_{PuT3}}$	$[22,32)$
$\boldsymbol{TT_{PuT4}}$	$[32,42)$
$\boldsymbol{TT_{PuT5}}$	$[42,52)$
$\boldsymbol{TT_{PuT6}}$	$[52,62)$
$\boldsymbol{TT_{PuT7}}$	$[62,+\infty)$
$\boldsymbol{TT_{CarRideH1}}$	$[0,10)$
$\boldsymbol{TT_{CarRideH2}}$	$[10,22)$
$\boldsymbol{TT_{CarRideH3}}$	$[22,+\infty)$

Although it is significant, when analysing the correlation among the different variables, there is evidence of significant correlation between $TT_{CarRideH1}$ used in the utility function of car alternative and $cost\_RideH$ ($robust\ correlation = -0.566$). This can be explained by the fact that the travel time values considered for the car alternative are the same for the ride-hailing one. Hence, the model cannot be considered valid and a new one was tested with the same estimated time coefficient in both utility functions. The results are presented in Table 4.9 and Table 4.10. The resulting utility functions and the analysis of the added parameter value is presented below:

$$V_{Car} = ASC_{car} + \beta_{TT1} \cdot TT_{CarRideH1}$$

$$V_{PuT} = ASC_{PuT} + \beta_{Many\_Days} \cdot Many\_Days$$

$$V_{RideH} = ASC_{RideH} + \beta_{TT1} \cdot TT_{CarRideH1} + \beta_{Long\_Haul} \cdot Long\_Haul + \beta_{GroupOf4} \cdot GroupOf4 + \beta_{1Child} \cdot Children1 + \beta_{cost_R} \cdot cost\_RideH$$

The journey time coefficient (β_{TT1}) for the ride-hailing and car alternatives ($TT_{CarRideH1}$) has a negative effect on both utilities, implying that if the time increases within the range of values $(0{,}10)$, the probability of choosing either mode decreases.

Table 4.9 - Estimated parameters values with three alternatives and alternative-specific parameters for travel cost and time used as categorical variables.

Parameter name	Variable description	Parameter value	t-statistic
ASC_{car}	-	0.00	-
ASC_{PuT}	-	-2.10	-5.43
ASC_{RideH}	-	0.998	3.81
β_{1Child}	1 if passenger travels with one child in V_{RideH}	1.22	2.46*
$\beta_{GroupOf4}$	1 if passenger travels with 4 more people in V_{RideH}	-2.43	-2.86*
β_{Long_Haul}	1 if passenger takes a long-haul flight in V_{RideH}	1.19	2.50*
β_{Many_Days}	1 if trip duration is longer than 7 days in V_{PuT}	-1.12	-2.00*
β_{TT1}	1 if travel time is lower than 10 minutes	-1.02	-2.17*
β_{cost_R}	Continuous variable for travel cost in V_{RideH}	-0.111	-6.46*

*Significant at the 5% level

Table 4.10 - Validation results model with three alternatives and alternative-specific parameters for travel cost and time used as categorical variables

Number of observations	260
Number of estimated parameters	8
Null log-likelihood ($\boldsymbol{L}(\boldsymbol{0})$)	-285.639
Log-likelihood ($\boldsymbol{L}(\boldsymbol{\beta})$)	-196.844
Likelihood ratio test	177.591

Table 4.11 and Table 4.12, shown below, present an overview of the different parameters and validation results of Model 1, Model 3 and Model 4 to allow a direct comparison.

Table 4.11 – Overview of the several parameters from models 1, 3 and 4.

Parameter name	Model 1		Model 3		Model 4	
	Parameter value	Robust t-statistic	Parameter value	Robust t-statistic	Parameter value	Robust t-statistic
ASC_{Car}	0.00	-	0.00	-	0.00	-
ASC_{PuT}	-1.93	-7.88	-0.273	-0.50	-2.10	-5.43
ASC_{RideH}	0.410	1.42	1.02	3.87	0.998	3.81

$\boldsymbol{\beta_{1Child}}$	0.996	2.20*	1.23	2.48*	1.22	2.46*
$\boldsymbol{\beta_{GroupOf4}}$	-2.11	-2.63*	-2.43	-2.86*	-2.43	-2.86*
$\boldsymbol{\beta_{Long\_Haul}}$	1.18	2.76*	1.18	2.48*	1.19	2.50*
$\boldsymbol{\beta_{Many\_Days}}$	-	-	-1.09	-1.93**	-1.12	-2.00*
$\boldsymbol{\beta_{cost}}$	-0.0834	-4.25*	-	-	-	-
$\boldsymbol{\beta_{cost_{PuT}}}$	-	-	-0.348	-2.53*	-	-
$\boldsymbol{\beta_{cost_R}}$	-	-	-0.111	-6.56*	-0.111	-6.46*
$\boldsymbol{\beta_{TT1}}$	-	-	-	-	-1.02	-2.17*

*Significant at the 5% level
**Significant at the 10% level

Table 4.12 - Overview of the several validation results from models 1, 3 and 4.

	Model 1	**Model 3**	**Model 4**
Number of observations	260	260	260
Number of estimated parameters	6	8	8
Null log-likelihood $(\boldsymbol{L(0)})$	-285.639	-285.639	-285.639
Log-likelihood $(\boldsymbol{L(\beta)})$	-207.925	-195.826	-196.844
Likelihood ratio test	155.428	179.626	177.591
Percentage of choice probability > 50%	-	25%	-

4.2.2. Choice set with two alternatives

Model 5: Common cost and time effect on alternatives

Observations with the chosen public transport option were excluded from the dataset to estimate the new model, thus considering only car and ride-hailing alternatives. Similar to the previous model, equal coefficients for travel time and cost variables were used for the first specification test. Nevertheless, results revealed that only the cost coefficient β_{cost} was relevant once again. Again, total estimation results are not reliable since there was not variance between data ($p = 1$).

Model 6: Alternative-specific parameters for travel cost and time used as continuous variables

Next, the alternative-specific parameters of travel time and cost were estimated. In this case, none of the estimated coefficients were found to be significant and results were not reliable once again.

Model 7: Alternative-specific parameters for alternative attributes, trip and passenger characteristics

The specification of car alternative is only composed by the ASC once again and the parameters were used in the utility form of the ride-hailing alternative. In this model, just the following two variables were found to be significant: $Claim\_Bag1$ (if the passenger had to claim one bag after arriving) and $cost_{RideH}$. However, when estimating parameters related to other variables expected to be relevant, the $cost_{RideH}$ revealed to be non-explanatory.

Model 8: Combined impact of all types of variables

Considering that only the $Claim\_Bag1$ and $cost_{RideH}$ were found to be explanatory variables even after several specification tests, other variables were jointly considered with the estimated parameter value representing their combined effect. The resulting utility functions are thereby given by:

$$V_{Car} = ASC\_Car$$

$$\begin{aligned} V_{RideH} = {} & ASC_{RideH} + \beta_{cost\_R} \cdot cost_{RideH} + \beta_{ClaimBag1} \cdot Claim\_Bag1 \\ & + \Big[\Big(\Big(\big((\beta_{Many1Child} \cdot Many\_Days) \cdot Children1\big) \\ & + \big((\beta_{busiL2000} \cdot business\_trip) \cdot L2000\big)\Big) \\ & + \big((\beta_{GenderShop} \cdot gender) \cdot Purchases\big)\Big) + \big((\beta_{genderLCC} \cdot gender) \cdot Low\_cost\big)\Big] \\ & + \big((\beta_{2BagLeisure} \cdot leisure\_trip) \cdot Plane\_Bag2\big) \end{aligned}$$

The final estimation results are presented in Table 4.13 and Table 4.14 and the analysis of the parameters' values is presented below:

- $\boldsymbol{\beta_{cost_R}}$: the travel cost coefficient has a negative effect on both utilities, implying that if the cost increases, the probability of choosing either mode decreases
- $\boldsymbol{\beta_{ClaimBag1}}$: if the passenger has to claim one bag after arriving ($Claim\_Bag1$), it is likely that she or he will use a private vehicle to egress the airport, which is illustrated by the coefficient with a negative sign
- $\boldsymbol{\beta_{Many1Child}}$: the combined effect of travelling with one child ($Children1$) and being more than seven days away from the place of residence ($Many\_Days$) has a positive effect, being an expected result due to possible high parking costs
- $\boldsymbol{\beta_{busiL2000}}$: passengers travelling for business purposes ($business\_trip$) and with a net income interval between 1000€ and 2000€ ($L2000$) are expected to prefer to drive and

park at the airport since usually the company pays for her or his trip. The negative sign of the coefficient is according to this assumption

- $\boldsymbol{\beta_{GenderShop}}$: the combined effect of being a female passenger ($gender$) and shop at the airport ($Purchases$) has a negative effect, which may imply women prefer to be picked-up by a family member or friend rather than take a taxi or Uber
- $\boldsymbol{\beta_{genderLCC}}$: a similar analysis to the one above can be deduced for women travelling with a low-cost airline company (Low_Cost)
- $\boldsymbol{\beta_{2BagLeisure}}$: passengers travelling for leisure purposes ($leisure\_trip$) and with two bags on the plane ($Palne\_Bag2$) are likely to prefer to drive and park at the airport as illustrated by the negative coefficient

Table 4.13 - Estimated parameters values with two alternatives and combined impacts.

Parameter name	Variable description	Parameter value	t-statistic
$\boldsymbol{ASC_{Car}}$	-	0.00	-
$\boldsymbol{ASC_{RideH}}$	-	1.68	4.50
$\boldsymbol{\beta_{2BagLeisure}}$	1 if passenger takes a leisure trip and have two bags on the plane in V_{RideH}	-1.32	-2.30*
$\boldsymbol{\beta_{ClaimBag1}}$	1 if passenger claims one bag in V_{RideH}	-1.17	-2.69*
$\boldsymbol{\beta_{GenderShop}}$	1 if passenger is a woman and shop at the airport in V_{RideH}	-1.60	-2.26*
$\boldsymbol{\beta_{Many1Child}}$	1 if the trip duration is longer than 7 days and passengers travels with one child in V_{RideH}	2.01	3.83*
$\boldsymbol{\beta_{busiL2000}}$	1 if passenger takes a business trip and has a net income between 1000€ and 2000€ in V_{RideH}	-1.92	-2.50*
$\boldsymbol{\beta_{cost_R}}$	Continuous variable for travel cost in V_{RideH}	-0.107	-5.89*
$\boldsymbol{\beta_{genderLCC}}$	1 if passenger is a woman and takes a low-cost flight in V_{RideH}	-1.04	-1.80**

*Significant at the 5% level
**Significant at the 10% level

Table 4.14 - Validation results with two alternatives and combined impacts.

Number of observations	203
Number of estimated parameters	8
Null log-likelihood ($\boldsymbol{L(0)}$)	-140.709
Log-likelihood ($\boldsymbol{L(\beta)}$)	-100.635
Likelihood ratio test	80.147
Percentage of choice probabilities: > 50%	65%

The validation test revealed that 65% of the observations were correctly estimated by the model with a probability higher than 50%. This is a much more successful result than the previous one.

Model 9: Alternative-specific parameters for travel cost and time used as categorical variables

As in the previous section, the parameters related to the different intervals of time and cost variables were estimated to try capturing their effect. Even though it was found significant, the parameter value $\beta_{TT_{R1}}$ of $TT_{CarRideH1} \in (0{,}10)$ in the ride-hailing alternative utility function is positive (Table A.4 in Appendix A.2), which is not in line with what was expected.

4.3. Discussion

4.3.1. Choice set with three alternatives

The mode choice model with three alternatives shows that travel cost, flight distance, trip duration, party size and number of children are significant variables. On the other hand, other factors expected to be significant such as the travel time, income, age, trip purpose, among many others were found to be non-explanatory and were excluded from the model.

For the travel cost, the estimated parameters with a negative sign for the ride-hailing and public transport utility functions are the expected result and are in accordance with the literature (Birolini et al., 2019; Harvey, 1986; Jou et al., 2011). When comparing both parameter values, it can be noted that for one unit increase in cost, the preference for the public transportation would be expected to decrease in a higher proportion (-0.348) than the ride-hailing reduction (-0.111). This can be due to the significant price differences between them. The cost of the car alternative was not found to have a significant effect on passenger behaviour which may be a result of the lack of parking charges responses (largest single cost component for the drive mode). Alongside with cost, travel time is commonly pointed in the literature as another explanatory variable (Birolini et al., 2019; Jou et al., 2011; Pels et al., 2003). However, in this study, results showed that time does not seem to explain the mode choice of Lisbon Airport's users, which might be due to its proximity to the city centre.

Looking at the party size variables, the results reveal that travelling with four more passengers will have a negative impact upon choosing the ride-hailing alternative. Even though the literature has usually revealed that the number of passengers decreases the probability of choosing public transportation rather than the ride-haling preference (Zaidan & Abulibdeh, 2018), it is consistent with previous research on the matter that larger groups are more attracted to rental car or drive and parking options. Besides that, it is worth of mention that a taxi or Uber for a group of five is typically more expensive than the usual one for a maximum of four passengers. Overall, this variable is the most affected factor for the mode choice since it will decrease the probability of choosing the ride-hailing alternative by 2.43 against the car option.

On the other hand, the odds for choosing the ride-hailing option are increased by the flight distance variable, meaning that passengers favour taxi or Uber options when taking long-haul flights. Passengers might avoid driving to alleviate the fatigue of the long journey they have just made or are about to make.

The probability of choosing the public transport mode decreases if the duration of the trip is longer than seven days. Longer trips usually mean more luggage and is therefore less expected to use the public transport to commute to or from the airport.

Finally, the not so obvious positive effect of travelling with one child in the ride-hailing probability may be explained by the fact that children are usually accompanied by their mother, who are more likely to favour taxi mode over driving as mentioned in the work of Gupta et al. (2008) and Harvey (1986).

4.3.1. Choice set with two alternatives

When excluding the public transport from the choice set, the estimated results show that the travel cost of the ride-hailing and number of claiming bags are the only two single explanatory variables. Besides that, the previous significant variables of flight distance, party size and number of children no longer influence the ride-hailing alternative. Again, travel time has no effect on the probability of choosing either the car or ride-hailing alternative as well as the cost upon the car choice. It is worth of mention that the negative effect of the ride-hailing cost is very similar to that on the previous model (-0.107 against the previous value of -0.111).

Findings on the number of bags are similar to previous research (Alhussein, 2011; Harvey, 1986). Travelling with extra luggage favours the use of private vehicle to egress the airport.

The combined impact of travelling with one child and making a trip longer than seven days was found to have a positive effect on the ride-hailing choice over the car. Besides the previously mentioned effect of travelling with one child, the preference for ride-hailing options is explained by the typically higher parking costs associated with longer trips, which is expected to increase the attraction of taking a taxi or Uber. These two variables combined are the most affected factors for the mode choice since it will increase the probability of choosing the ride-hailing alternative by 2.01 against the car option.

The combined negative effect of being a female passenger and make purchases at the airport upon choosing to take a taxi or Uber is not such a straightforward assumption and is against previous research. However, this result may reflect a preference specifically for the picked-up or dropped/off option rather than drive and parking.

Alongside with this effect, results also revealed that being a female passenger and travelling with a low-cost company decreases the probability of taking a taxi or Uber. A similar explanation to the above-mentioned may be given.

Furthermore, the odds for choosing the ride-hailing option are decreased if the passenger travels for business purposes and has a net income higher than 1000€ but below 2000€. Such findings are in accordance with the literature that associates business trips with shorter trips (Harvey, 1986), which are also often paid by the passenger's company (Birolini et al., 2019; Chebli & Mahmassani, 2002), and therefore encourages business travellers on choosing to drive and park at the airport. Besides that, higher incomes are usually associated with favouring the car alternative.

Finally, looking at the mixed effect of travelling for leisure purposes and with two bags on the plane, the results reveal that it has a negative effect upon the probability of choosing the ride-hailing alternative once again. Leisure trips are usually associated with longer trips and thereby a higher number of bags, which tend to favour the car mode choice (Alhussein, 2011).

5. Conclusion

This dissertation aims to expand the current literature on airport access mode choice models by assessing the passenger behaviour of the Lisbon Airport. Additionally, it is also the first work up to date on passenger's behaviour modelling considering TNCs like Uber in the set of access mode alternatives.

According to the literature, usually access choice is mainly influenced by trip factors such as travel time and cost, trip purpose, party size, among many others, but also by passenger characteristics like income, residence status, nationality or age. Yet, the literature indicates that non-business passengers are significantly more affected by these demographic characteristics than those for business passengers.

A prior analysis of the main conclusions on the passenger mode choice in the literature helped conducting the present research for the case of Lisbon Airport. For that purpose, it was gathered data through a revealed stated preferences survey questionnaire on several trip and socioeconomic characteristics. The survey statistical results show that most of the respondents preferred to be picked-up or dropped-off by someone (31.4%) to access or egress the airport and a fifth (20.7%) chose to use a ride-hailing option, with drive and park representing the third most chosen alternative (18.2%).

Regarding the choice set considered to model the current mode choice, three alternatives were defined: car, ride-hailing and public transport. Several specification tests were developed, and an extensive analysis of the explanatory variables were conducted to ensure the accuracy of the resulting models. Overall, the explanatory variables used to model passenger behaviour are the ones already mentioned in the literature: travel cost, flight distance, number of bags on the plain and need to be claimed, party size and number of children, trip duration, gender, shop at the airport, travelling airline company, trip purpose and income. However, many other factors expected to be significant based on the literature were tested but found to be non-explanatory, such as travel time, age, nationality, among many others.

At the end, two types of MNL models were obtained: the ones considering the choice set with three alternatives and the others including just the car and ride-hailing options. On total, nine different MNL models were obtained. Based on a validation test, only 25% of the observations left aside for this purpose were correctly estimated by model 3 with a probability higher than 50%. On the other hand, model 8 was found to be much more successful than the former, with 65% of the observations being correctly estimated.

Results of this study reveal important and useful empirical data that can be used to inform airport authorities on current practices and help them meeting the ground accessibility needs of Lisbon Airport's users, while providing new solutions that accompany the fast-growing mobility service industry.

5.1. Limitations and future work

Although the findings of this work may give indications on the current Lisbon Airport accessibility behaviour, further studies are required to strengthen the knowledge regarding this issue and address some of the limitations of this work. A sample size of 319 observations can be considered as representative when considering that it mainly represents local people of the Metropolitan Area of Lisbon using the airport. However, it might be limited and the MNL models may overestimate the parameters' values (β). Accordingly, the interpretation of the model results must be carried out with some caution and a larger size sample after the end of the coronavirus pandemic should be used in future studies for a more robust and accurate analysis.

Furthermore, data on foreign passengers is very limited in this study due to a restricted network and a lack of time resource. Therefore, analysing the behaviour of foreigners would be useful in future studies as they represent a significant portion of the airport population and may have different access mode preferences.

Considering the results obtained in this dissertation, public transport was found to be the least chosen mode of transport to commute to/from Lisbon Airport. Hence, future research may focus on establishing strategies to increase the attractiveness of the public transport system. Such studies will assist Lisbon authorities in using strategic planning to improve the transportation and tourism integration. As a result, public authorities would gain competitive advantages over neighbouring airports and thereby increasing revenues.

Finally, a similar analysis should be applied in the Porto and Faro cities to increase the degree of knowledge on airport accessibility in Portugal.

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Appendix

A.1. Survey questions

Table A.1. - Survey questions about the access of Lisbon Airport.

Question	Answer	Question	Answer
Have you ever used the Lisbon Airport?	Yes No		
When did you use it for the last time?	Ex: January 2019		
Was this the first time you used the Lisbon Airport?	Yes No		
What is your nationality?	Portuguese European North American South American Asian African Other		
Do you live in Portugal?	Yes		
	No	**Which country do you live in?**	United Kingdom France Spain Belgium Netherlands Italy Switzerland Germany Ireland Other
What kind of flight were you undertaking the last time you used the Lisbon Airport?	Outbound flight from Lisbon Airport (i.e., departing from Lisbon) Inbound flight to Lisbon Airport (i.e., arriving in Lisbon)	**What was the destination/origin (city) of the flight?**	London Paris Madrid Barcelona Funchal Ponta Delgada Brussels Amsterdam Roma

Table A.1. - Survey questions about the access of Lisbon Airport (Continuation).

Question	Answer	Question	Answer
			Geneva
			Milan
			Sao Paulo
			Dublin
			Zurich
			Sevilla
			Valencia
			Lyon
			Casablanca
			Bilbao
	Connecting flight		
Which airline company did you travel with?	Blue Air		
	easyJet		
	Norwegian		
	Ryanair		
	Transavia		
	Wizz Air		
	TAP		
	Lufthansa		
	iberia		
	Emirates		
	KLM		
	Other		
How many days approximately were you away from your place of residence?	Ex: 5		
What was the purpose of that trip?	Business	**Who paid for your trip?**	The company you work for
			Yourself
	Holiday/leisure		
	Visit relatives/friends		
	Other		
What was the week day of your departure/arrival?	Monday/Tuesday/Wednesday/Thursday		
	Friday		
	Weekend		

Table A.1. - Survey questions about the access of Lisbon Airport (Continuation).

Question	Answer	Question	Answer
How did you leave/arrive at the airport?	Own private vehicle	**How much did you pay for parking charges?**	Ex: 10€
	Picked-up/dropped-off by family member, friend, colleague or other Aerobus Hotel transfer service Taxi Metro Train Bus Ride-hailing provider (Uber, Bolt, Kapten, Cabify, myTaxi, Izzy Move, etc.) Car-sharing provider (BlaBlaCar, Deboleia, Boleia.net, CarpoolWorld, GalpShare, Europe Carpooling, etc.) Emov	**Have you ever used the parking lot of the airport?**	Yes* No
		How much did the trip from/to the airport cost?	Ex: 2€
		How did you pay?	Card Direct debit or Paypal Cash
		Did you withdraw money before?	Yes No
	Rental car	**Did you have parking lots at your accomodation?**	Yes No
		Have you ever used the parking lot of the airport?	Yes* No
	Other		
***Why didn't you use your own private vehicle and parking this time?** Please select a maximum of 3 reasons.	It was more expensive than what I used Parking cost Do not own a private vehicle in Lisbon anymore No parking lot at home or hotel/rented residence Less convenient than other mode Traffic Company payed my taxi, uber, bolt, etc. Environmental concerns Other		

Table A.1. - Survey questions about the access of Lisbon Airport (Continuation).

Question	Answer	Question	Answer
Did you arrive at the airport directly from your accomodation?/ Did you go directly to your accomodation when you arrived at the airport?	Yes	**Where is your accomoodation located?**	Ex: Arroios Lisbon
	No	**Where is that place from where you arrived/went after arriving at the airport located?**	Ex: Arroios Lisbon
How long have you been outside the transportation mode (e.g. time needed to access the parking space or station on foot, waiting time until the transportation mode arrived, transfers time between modal shifts, etc.)?	Less than 5min 5 to 15min 16 to 30min More than 30min		
When did the ground trip from the airport occur?	Morning Afternoon Night I don't remember		
Please rank the main 3 reasons for choosing that transportation mode, being the first one the most relevant.	Price Comfort in vehicle Easiness with bag transfer Safety Journey time Convenience Environmental concerns		
Would you use it another time?	Yes		
	No	**Why not?** Please select the main reason.	Price Journey time Waiting time until the transportation mode arrived

Table A.1. - Survey questions about the access of Lisbon Airport (Continuation).

Question	Answer	Question	Answer
			Walking distance to/from the parking lot Difficulty with bag transfer Number of transfers (between modal shifts) Transfers time between modal shifts Other
How well do you know all the available alternatives to access/leave the airport?	1 (no idea which are the available alternatives) 2 3 4 5 (know very well all the available alternatives)		
Please select the option that best describes you. I slept well the night before my flight	Totally disagree Mostly Disagree Somewhat Disagree Neither Agree or Disagree Somewhat Agree Mostly Agree Totally Agree		
Please select the option that best describes you. My flight was long	Totally disagree Mostly Disagree Somewhat Disagree Neither Agree or Disagree Somewhat Agree Mostly Agree Totally Agree		
Please select the option that best describes you. My flight departed later than scheduled	Totally disagree Mostly Disagree Somewhat Disagree Neither Agree or Disagree Somewhat Agree Mostly Agree Totally Agree		

Table A.1. - Survey questions about the access of Lisbon Airport (Continuation).

Question	Answer	Question	Answer
Please select the option that best describes you. I moved easily within the airport without getting lost	Totally disagree Mostly Disagree Somewhat Disagree Neither Agree or Disagree Somewhat Agree Mostly Agree Totally Agree		
How much time before the scheduled flight departure time did you arrive at the airport?	Less than 30 min 30min to 45min 45min to 1h 1h to 1h15 min 1h15min to 1h30 min 1h30 min to 1h45 min 1h45min to 2h 2h to 2h15min 2h15 to 2h30min More than 2h30min		
Please select the stress level you felt of losing your flight.	1 (not stressed at all) 2 3 4 5 (very stressed)		
Did you use the Fast Track service?	Yes No		
Did you use the business lounge?	Yes No		
Did you make any purchases in the airport?	Yes No		
How did you check-in?	Online Mobile application At the airport counter At the airport's automatic machine Other		

Table A.1. - Survey questions about the access of Lisbon Airport (Continuation).

Question	Answer	Question	Answer
How many baggage did you have to check-in?	0 1 2 3 More than 3		
How many hand-baggage did you have in the plane with you?	0 1 2 3 More than 3		
How many people did you travel with?	0 1 2 3 4 More than 4		
How many of them were children?	0 1 2 More than 2		
Were there people who need physical assistance?	Yes No		
Was it raining that day?	Yes No I don't remember		
Did you use the same option to previously leave the airport when arrived/departed in/from Lisbon?	Yes		
	No	**Why not?** Please select the main reason.	Price Journey time Waiting time until the transportation mode arrived Walking distance to/from public transportation stations Walking distance to/from the parking lot

Table A.1. - Survey questions about the access of Lisbon Airport (Continuation).

Question	Answer	Question	Answer
			Dificulty with bag transfer Number of transfers (between modal shifts) Transfers time between modal shifts
How often do you travel by plane per year? Please consider one trip as one departure and arrival.	0 to 3 trips per year 4 to 12 trips per year More than 12 trips per year		
How often do you use the Lisbon Airport per year? Please consider one trip as one departure and arrival.	0 to 3 trips per year 4 to 12 trips per year More than 12 trips per year		
How old are you?	18 to 24 years old 25 to 34 years old 35 to 44 years old 45 to 54 years old 55 to 64 years old More than 64 years old		
What is your gender?	Male Female Prefer not to say		
How would you describe your household net monthly income in € (roughly)? Please include all types of income, including monthly wage, salary, income from self-employment, pension, child allowance, housing benefit	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 say		

Table A.1. - Survey questions about the access of Lisbon Airport (Continuation).

Question	Answer	Question	Answer
or social assistance, and other income after deducting taxes and social security contributions for all household members.			
What was your employment status the period of the flight?	Full-time worker Part-time worker Self-employed Student Not employed Other		
What is your basic transportation mode to work in your home city?	Car Motorcycle Metro Bus Train Walking Other		
How far away is your accommodation from the closest bus/metro/train station? Please consider that 1km is approximately 10 minutes walking time.	0 to 1km More than 1km		
And how far away is your work from the closest bus/metro/train station?	0 to 1km More than 1km		
Do you have a driving license?	Yes	**How many vehicles do you own?**	0 1 2 More than 2
	No		

Table A.1. - Survey questions about the access of Lisbon Airport (Continuation).

Question	Answer	Question	Answer
Can you move independently or do you need any type of physical assistance?	I can move independently I need physical assistance		
Is there any ride-hailing provider (Uber, Bolt, Lyft, etc.) available in your home town?	Yes	**How often do you use them?**	Never Very Seldom Seldom Sometimes Often Very Often Every Day
		How much satisfied are you with them?	Totally Dissatisfied Dissatisfied Somewhat Dissatisfied Neither Satisfied nor Dissatisfied Somewhat Satisfied Satisfied Totally Satisfied
	No I do not know		
Is there any taxi application service in your home town? (E.g. taxi.eu, Gett, mytaxi, Izzy Move, etc.)	Yes	**How often do you use them?**	Never Very Seldom Seldom Sometimes Often Very Often Every Day
	No I do not know		
Is there any car-sharing provider (BlaBlaCar, CarpoolWorld, GalpShare, etc.)	Yes	**How often do you use them?**	Never Very Seldom Seldom Sometimes Often

available in your home town?		Very Often Every Day
	No I do not know	

A.2. Results of the accessibility models

Table A.2 - Estimated parameters values with three alternatives and alternative-specific parameters for travel cost and time used as continuous variables (excluding the $\boldsymbol{cost\_PuT}$).

Parameter name	Variable description	Parameter value	t-statistic
$\boldsymbol{ASC\_Car}$	-	0.00	-
$\boldsymbol{ASC\_PuT}$	-	-1.69	-6.25
$\boldsymbol{ASC\_RideH}$	-	0.896	3.58
$\boldsymbol{\beta_{1Child}}$	1 if passenger travels with one child in V_{RideH}	1.23	2.51
$\boldsymbol{\beta_{GroupOf4}}$	1 if passenger travels with 4 more people in V_{RideH}	-2.40	-2.82
$\boldsymbol{\beta_{Long\_Haul}}$	1 if passenger takes a long-haul flight in V_{RideH}	1.19	2.53
$\boldsymbol{\beta_{Many\_Days}}$	1 if the trip duration is longer than 7 days in V_{PuT}	-1.03	-1.77
$\boldsymbol{\beta_{cost\_R}}$	Continuous variable for travel cost in V_{RideH}	-0.105	-6.33

Table A.3 - Validation results with three alternatives and alternative-specific parameters for travel cost and time used as continuous variables (excluding the $\boldsymbol{cost\_PuT}$).

Number of observations	260
Number of estimated parameters	7
Null log-likelihood $(\boldsymbol{L(0)})$	-285.639
Log-likelihood $(\boldsymbol{L(\beta)})$	-199.060
Likelihood ratio test	173.158

Table A.4 - Estimated parameters values with two alternatives and alternative-specific parameters for travel cost and time used as categorical variables.

Parameter name	Variable description	Parameter value	t-statistic
$\boldsymbol{ASC\_Car}$	-	0.00	-
$\boldsymbol{ASC\_RideH}$	-	-0.239	-0.41
$\boldsymbol{\beta_{ClaimBag1}}$	1 if passenger claims one bag in V_{RideH}	-0.926	-2.34
$\boldsymbol{\beta_{TT\_R1}}$	1 if travel time is lower than 10 minutes	1.18	2.41
$\boldsymbol{\beta_{cost\_R}}$	Continuous variable for travel cost in V_{RideH}	-0.0456	-2.05