The impact of railway transfers on long-distance travel in Europe

A stated-choice experiment on leisure travellers

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TU Delft

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TU Delft

Preface

Dear reader,

This thesis illustrates the final dot to my master's in Transport and Planning. After nine long years since I started my bachelor's in Geography and Planning in France, punctuated by a few (way too long and too many) study breaks along the way, stops in Ireland and in Spain before arriving in the Netherlands, my student life is finally coming to an end.

I would like firstly to thank my supervisors from TU Delft for the help they provided me over the last 14 months I have been working on my thesis. I would like to thank my chair, Oded, for his help in finding this subject that I really enjoyed working on. I would like to thank Eric for his help with the technical aspects of my research such as the design of the survey and the choice modelling. Thank you Nejc for your constant support, encouragement, availability and feedback all along the process.

I would also like to thank all of my amazing friends from university, who have been there for me in the happy, but also the most difficult moments. Thank you Stavro, Matéo, Ruben (1), Mathijs, Marc, Schelte, Nao, Eva, Sandro, Ruben (1bis) and Arjan.

Finally, I would like to thank my parents and my sisters for their continuous support despite the distance.

I hope you will enjoy reading my thesis, as much as I had writing it.

B.A.T.M.R de Pindray

Delft, August 2024

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1 Summary

The transportation sector significantly impacts the environment, contributing to 29.4% of the European Union's greenhouse gas (GHG) emissions in 2021. International efforts have been made to mitigate this impact, such as the implementation of the European Green Deal, aiming for a 90% reduction in transport-related emissions by 2050. Despite these efforts, long-distance travel, particularly by air and road, continues to contribute heavily to GHG emissions, driven by less sustainable modes like planes and cars. Rail transport, though a more sustainable option, remains underutilized, accounting for a small share of long-distance travel in Europe. Transfers in railway journeys have been identified as a major barrier to the wider adoption of rail travel. These transfers can increase travel time, induce stress, and reduce comfort, making rail less attractive compared to other modes. This study seeks to understand how railway transfers affect traveller behaviour and mode choice in long-distance leisure travel across Europe. To meet this objective, this study aims to answer the following research question:

To what extent do railway transfers impact passengers' mode choice in long-distance leisure travel in Europe, and what are the associated penalties and preferences to railway transfers?

To answer the research question, interviews were first conducted at major train stations in the Netherlands, helping to determine the most important attributes of railway transfers for travellers for international travel in Europe. After a thematic analysis of the answers, the most important elements concerning railway transfers were found to be transfer time, potential delay of the first train, frequency of the second train and transfer type. This information was then inputted in the design of a stated preference survey, where they were used as the attributes to be estimated, in the choice between four alternatives, two trains with transfer, a direct train, a plane and a car. This survey aimed to quantify the trade-offs made by travellers between various aspects of railway transfers in the context of leisure travel for a distance of about 500 kilometres in Europe. The survey was distributed both online and in-person, mostly in the Netherlands between April and May 2024, and led to the collection of 1616 choice observations.

Two discrete choice models were applied to analyse the data collected from the survey: a Multinomial Logit (MNL) and a panel Mixed Logit (ML) model. With these models, the parameter values of the attributes of the survey were estimated to assess the importance of various transfer-related attributes on mode choice. These models are based on the random utility maximisation (RUM) theory, stating that travellers are choosing the options that they consider maximising their utility.

With the MNL model, travel time and travel cost were first tested as alternative specific parameters. Then different interactions between transfer-related parameters were tested, followed by testing the non-linearity of the transfer time attribute parameter, both with a quadratic and cubic term. A base model was determined, including transfer time non-linearity. Interactions of the attributes with the sample socio-demographics and travel habits were then tested and the most significant interactions were kept in the final MNL model.

A panel mixed logit model was then estimated, to account for the panel structure of the data, as eight choices were offered to each participant. Estimating a mixed logit model allowed testing for heterogeneity preferences among the travellers. All the attribute parameters were tested as randomised

parameters and were kept in the model if their standard deviation was found to be highly significant, showing an important variation in taste for the associated attribute.

The respondents to the survey were mostly young people younger than 30 years, students or working full time, and who had completed a higher level of education, such as a bachelor's or a master's degree. Furthermore, the respondents were almost evenly split between male and female and a majority were able to drive or to have access to a car. Their travel habits were accounted for, more specifically for long-distance trips with distances higher than 100 kilometres, internationally in Europe. The participants of the survey were mostly used to undertaking this kind of trip, with almost 80% of them going on similar trips at least twice a year, using planes, trains or cars to do so. Furthermore, they had experience with railway transfers in the past, for more than two-thirds of them. The sample was compared to the Dutch population, as the survey was mostly answered by Dutch inhabitants. Besides the gender, the sample was found to be statistically different from the dutch population.

The results from the Multinomial Logit (MNL) model revealed significant preferences and aversions among travellers regarding different travel modes and railway transfers. Initial preferences were captured through the Alternative Specific Constants (ASCs), which indicated strong preferences for direct modes of travel over trains with transfers. The ASCs for car, plane, and direct train were all found to be positive and significant, suggesting that travellers prefer these options more than the train with transfer. The direct train and car showed the highest ASC values, emphasising a strong aversion to transfers. The willingness-to-pay (WTP) analysis quantified that travellers are willing to pay approximately 49€, 48€ and 32€ to travel a transfer and travelling by car, direct train and plane respectively, instead of enduring railway transfers. Furthermore, the MNL model analysis showed that all transfer-related attributes, such as travel time, cost, and delays, negatively impact the utility, while transfer time itself has a positive contribution. Travel time and cost were found to be highly significant, with travellers being particularly sensitive to cost, even more so for those with lower incomes or the one having previous transfer experiences. Transfer time's utility contribution follows a non-linear relationship, increasing at a decreasing rate, suggesting a diminishing positive contribution to utility as transfer time grows. Additionally, travellers showed a strong dislike for cross-station transfers compared to cross-platform ones, with escalator transfers being particularly disliked. The penalty for cross-station transfers was estimated at 20.3 minutes of additional transfer time or 16.42€. Lower train frequency at transfer stations also negatively impacts utility, though this factor is less significant compared to others.

The mixed panel logit models initial estimates revealed significant heterogeneity in preferences, particularly for the Alternative Specific Constants (ASCs), escalator use, frequency, delay, and transfer time. Parameters for lifts and the square and cubic terms of transfer time were deemed non-significant and removed in the final model. The final mixed panel logit models confirmed significant variation in preferences for ASCs, indicating that travellers have diverse initial preferences for different travel modes, especially car and plane compared to trains with transfers. For transfer-related attributes, while heterogeneity was evident in how different attributes affected utility, the frequency of the second train showed the greatest variability in impact among travellers. The results underscore the importance of accounting for individual differences in travel preferences when evaluating the effects of different attributes on utility.

The panel mixel logit model accounting for all the ASCs as randomised parameters was found to be the most performing model out of all models estimated in the study. This model was then used to determine market shares based on different scenarios. Various scenarios were tested to evaluate how changes in alternative characteristics affect market share. The base scenario involved a travel time of 5 hours and 30 minutes, a travel cost of €90, a cross-platform transfer, a 5-minute average delay of the first train, a 30-minute transfer time, and a second train frequency of one train per hour. In scenario 1, the transfer type was changed from cross-platform to cross-station with an escalator. This scenario reveals a significant drop in market share for trains with a transfer, a notable increase for direct trains, and slight increases for planes and cars. The results indicate that cross-station transfers are a major deterrent, suggesting that operators should aim to provide transfers on the same platform to retain more passengers. In scenarios 2 and 3, cost changes were explored. Scenario 2 applies a €15 reduction to the train with a transfer, while Scenario 3 increases the plane's travel cost by €15, simulating a carbon tax. Increasing the plane's cost was found to be more effective in reducing its market share, indicating that financial penalties can influence mode choice significantly. In scenario 4, the impact of reducing the frequency of the second train to one every two hours, compared to the base scenario of one train per hour, was examined This decrease prompted a shift from train with transfers to direct trains, and also slightly affected car and plane market shares. The findings suggest that lower train frequencies at transfer points lead to higher anxiety about missed connections, underscoring the importance of optimising transfer connections or improving frequency for railway operators to maintain or increase railway market share.

2
Introduction

2.1. Problem description and scope

The transportation sector has a high impact on the environment, accounting for 29.4% of greenhouse gas (GHG) emissions at the EU level in 2021 (Ministry of the Energy Transition, 2023) and can be considered as “one of the key contributors to past and future climate change” (Aamaas et al., 2013). Consequently, addressing and mitigating the transportation sector’s environmental impact has gained substantial importance at international levels. For instance, the European Commission (EC) is currently implementing various measures through the European Green Deal and its sustainable and smart mobility strategy, with one of its main objectives, to achieve the target of a 90% reduction in GHG emissions caused by the transport sector by 2050, compared to 1990 emissions levels (Commission, 2019).

Studies have emphasised that even though long-distance travels only represents a small part of the total number of trips made within Europe, they contribute largely to the overall share of passenger-km travelled (PKT) per year, with 55% for trips longer than 100 kilometres and 20% for trips longer than 300 kilometres (Aparicio, 2016). Consequently, long-distance travels have an important responsibility in the high GHG emissions of the transport sector (Aamaas et al., 2013; Christensen, 2016; Mabit et al., 2013; Malichová et al., 2022). This impact is projected to continue to rise, as in recent years, a significant increase in the number of long-distance trips within Europe as well as distances covered has been witnessed, primarily driven by less environmentally friendly modes such as planes and cars (Witlox et al., 2022).

In 2022, aviation contributed to 13.9% of GHG transport emissions and road transport contributed to 77% of GHG transport emissions in the EU. In contrast, rail transport contributed to only 0.4% of these emissions (Agency, 2024). The lower emissions associated with rail transport can be attributed to factors, such as the power supply and the vehicle propulsion type used, making it a more sustainable alternative than air and route-based modes. The modal shift from the use of planes and cars to more sustainable transportation modes such as high-speed rail (HSR) and conventional rail is seen as a “crucial initiative” (Avogadro et al., 2021) and has been demonstrated to be beneficial for the climate in various studies (Aamaas et al., 2013; Baumeister, 2019; Borken-Kleefeld et al., 2013; Dalkic et al., 2017; Kamga & Yazici, 2014). A comparative study of emissions per modes in different corridors in Spain revealed that between Madrid and Barcelona, the use of conventional rail over plane could lead to a decrease of around 75% of carbon dioxide emissions (CO2), which is the predominant GHG, per passenger. These environmental benefits further increase with High-Speed Rail demonstrating a reduction of 81% in CO2 emissions compared to air travel (Álvarez, 2010).

At the EU level, policies to encourage a modal shift from less sustainable modes to railways have been developed by the European Commission, such as the Action Plan, whose main objective is to “boost long-distance and cross-border passenger services” (Commission, 2021a). The EC’s sustainable and smart mobility strategy sets targets of doubling the high-speed rail traffic by 2030 and tripling it by 2050 (Commission, 2020). Recognising the safety and environmental benefits of rail transportation, the European Commission emphasises that rail remains one of the cleanest and safest modes of transport. Consequently, it plays a central role in their efforts to establish more sustainable mobility throughout the European Union (Commission, 2021b). At a country level, in 2020 and 2023, Austria and France implemented bans on domestic short-haul flights, restricting routes where direct rail alternatives with travel times of less than 3 hours for Austria and less than 2.5 hours for France were available (Euronews, 2023). Nevertheless, these measures have been proven to be ineffective in mitigating the environmental impact of air travel (Dobruszkes et al., 2022) and could potentially generate external costs (Cantos-Sánchez et al., 2023). Despite the efforts made to promote the use of railways by making them more attractive to passengers, they still account for a small share of long-distance travel compared to less sustainable modes such as planes and cars (Eurostat, 2024). At the European level, international rail transport holds around 7.8% of the modal share in 2021 and experienced a decline in recent years (Witlox et al., 2022).

To promote the transition towards more sustainable modes of transportation for long-distance travel, such as trains, it is crucial to analyse the behaviour and preferences of travellers and study their travel patterns. This analysis is essential for gaining a deeper understanding of their needs and facilitating the adoption of more environmentally friendly transportation options for long-distance journeys (Malichová et al., 2022).

Transfers in railway have been identified as a potential bottleneck to the largest use of the railway network for long distances in Europe, because it influences the comfort of travellers, alongside journey time, cost and planning (Witlox et al., 2022). Furthermore, Guis and Nijënstein, 2015 described the attractiveness of passengers to a journey by railway by being determined by three main elements: the travel time, the existence of transfers and their convenience, and if the train operates when the traveller needs it, determined by frequency and departing time. Transfers are described in the literature as inducing high stress to passengers, uncertainty, as well as discomfort and they are associated with a transfer penalty that influences travellers' choices (Guo & Wilson, 2011) and impacts the attractivity of passengers for an itinerary or mode of transport. They impact different levels of the pyramid of customer needs, illustrating passenger preferences when travelling (van Hagen et al., 2019), presented in Figure 2.1.

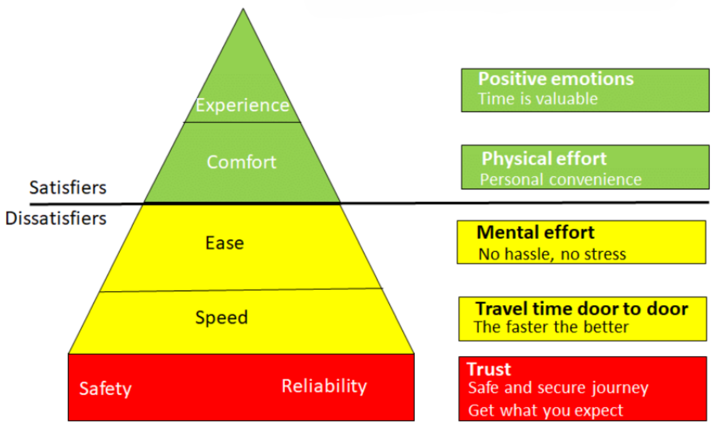

Figure 2.1: Pyramid of customers needs (van Hagen et al., 2019)

The level "Speed" can be impacted as a transfer can increase the total journey time, especially in case of a delay or a missed connection. The journey time can be particularly impacted as time spent waiting outside of the transport mode can be perceived as higher than in-vehicle time (Ceder et al., 2013). Transfer can also impact the levels of "Ease" as a transfer can increase the mental effort linked to hassle and "Stress" that can be created by a transfer, but also the "Comfort" level with the physical effort induced by making a transfer. Studying transfer-related attributes will allow to gain more understanding of travellers' mode choice in long-distance travelling, as transfer are seen as a key barrier in the use of rail.

A majority of research on long-distance travel behaviour has focused on investigating attributes such as travel time and travel cost, and their relative impact on passengers' mode choice and future demand (Behrens & Pels, 2012; González-Savignat, 2004; Mabit et al., 2013; Martín & Nombela, 2007). The findings of these studies underlined the importance for passengers of travel cost (Park & Ha, 2006) and of both travel time and travel cost (González-Savignat, 2004) in the mode choice between HSL (high-speed line) and plane, as well as in the mode choice between rail, bus, car and plane (Martín & Nombela, 2007). Differences in the importance of attributes were also noted between different travellers, with train and car travellers more sensitive to changes in travel time, while plane travellers exhibiting a higher sensitivity to travel costs variations (Mabit et al., 2013; Martín & Nombela, 2007). Furthermore, the frequency of HSL has been proven to be crucial in addition to travel time in the substitution potential of HSL to plane (Behrens & Pels, 2012).

In addition to attributes such as travel time, travel cost and frequency, other studies on travel behaviour have frequently included service quality attributes into their research, such as reliability (Bergantino & Madio, 2020; Ortúzar & Simonetti, 2008; Román et al., 2007) and comfort (Heufke Kantelaar et al., 2022; Lakatos & Mándoki, 2020; Ortúzar & Simonetti, 2008; Román et al., 2007). Reliability has been explored in various dimensions within the literature. Román et al., 2007 investigated its effects by studying the impact of delays on travellers, while Bergantino and Madio, 2020 studied the probability of being on time. Comfort was also defined differently in diverse studies, being the leg room and seat's width (Román et al., 2007), class type and service delay (Ortúzar & Simonetti, 2008) in railway and plane or the access to toilets in trains (Lakatos & Mándoki, 2020). Trade-offs between travel time and comfort and travel cost and reliability have been observed with travellers being more sensitive to time savings if comfort is lower and travellers planning to use HSL ready to pay more in order to minimize delays (Román et al., 2007). Trade-offs between travel time, travel cost and comfort according to distance travelled in train have also been observed, with travellers willing to pay more and have a larger travel time for comfort, as well as willing to pay more for smaller time savings when the distance travelled increase (Lakatos & Mándoki, 2020). Furthermore, the impact of contexts on travel choices has also been noted with business travellers being less sensitive to comfort and more sensitive to travel time savings compared to leisure travellers (Lakatos & Mándoki, 2020).

However, even though transfer has been considered as a factor that could influence the behaviour and choices of travellers, a limited amount of research exists on the impact of transfer-related attributes in transportation, especially in the context of railway transfers in long-distance travelling. Most of the literature on travelling behaviour considering transfer-related attributes has been related to plane transfer for long-distance travelling or multimodal transport at an urban level for commuters, as will be seen later in this study.

2.2. Research objective and research questions

As highlighted in the previous section, acquiring a deeper understanding of traveller behaviour and needs in long-distance travel is important for encouraging a shift from less sustainable modes such as planes, to the use of railways. While attributes like travel time and costs have been extensively studied, it is necessary to consider additional attributes, such as parameters related to transfer, that is considered an obstacle in the increase of the use of rail for long-distance travel. The main objective of this research is to gain insights into the behaviour of long-distance travellers when transfer(s) are included in railway trips, and this way to gain more knowledge on the impact of railway transfers on mode choice.

To achieve that goal, the main research question that will be answered in that research is the following:

To what extent do railway transfers impact passengers' mode choice in long-distance leisure travel in Europe and what are the associated penalties and preferences to railway transfers?

To answer the main research question, three sub-questions have been formulated:

1. *Which attributes do travellers consider important in a railway route including a transfer in long-*

distance travelling?

2. *What is the extent of the initial dispreference for railway transfers in long-distance leisure travel?*
3. *To what extent do the key attributes influencing traveller's behaviour on train routes with transfers impact preferences for this mode for leisure long-distance travel?*

2.3. Scientific and societal relevance

The scientific contribution of this research is on one side to gain a deeper understanding of long-distance traveller behaviour and on the other side on the impact of railway transfers on traveller behaviour. Traveller behaviour research has been predominantly focused on urban travel, and since long-distance travel is growing, there is a need to expand the knowledge on this topic, as traveller behaviour and preferences could be different for these distances compared to smaller distances. Additionally, this research help bridge the existing gap in literature exploring the impact of railway transfer on travel behaviour, as transfer-related attributes have received limited attention compared to other travel-related attributes. Furthermore, existing studies on mode transfers have been more focused on airplane transfers and multimodal transfers. Overall, this research is contributing to gaining more insights into the factors encouraging and discouraging a shift towards the use of railways for long-distance travel.

This research benefits at the societal level by providing recommendations on measures that could be implemented to reduce the disutility associated with railway transfers and make railways more attractive for long-distance travelling in Europe. These recommendations could be shared with policymakers and public transport operators in Europe, as part of their effort to make rail more attractive to passengers for long-distance travel and encourage a shift from air travel and car travel to rail, in a context where direct railway routes are not always available.

2.4. Report structure

The report will start by presenting in Chapter 3 the literature review on transfers in travel behaviour studies. Then the methodology that will be used to answer the different sub-research questions will be developed in Chapter 4. This will include the conception of the interviews and the survey, as well as the methods used to analyse the data gathered. In Chapter 5, the results of the interviews will be given. In Chapter 6, the conception of the survey will be explained, followed by an analysis of the results using discrete choice modelling in Chapter 7, Finally, in Chapter 8, conclusions of the research will be drawn and discussions and limitations of the research and its results will be given.

3
Literature review

In this chapter, the current body of research on the impact of mode transfer on travellers' behaviour is presented, and the existing gaps in the literature are highlighted. The goal is to gain more insights into the current literature on passenger travel behaviour, where transfer-related attributes have been studied and analysed. First, the methodology used to identify relevant literature is described in Section 3.1. Next, the literature focusing on transfers during short and medium-distance trips is discussed in Section 3.2, followed by the literature concerning transfers in long-distance travel in 3.3. The findings are categorised based on the research methodology used and the type of transfer-related attributes analysed. Finally, research gaps identified in the literature are highlighted, and conclusions are drawn in Section 3.4.

3.1. Methodology

The literature review process starts by using search engines Google Scholar and Scopus, employing keywords such as "mode choice", "railway transfer", "railway connection", "transfer", "connection", "long-distance travel", "passenger behaviour" and "choice modelling". These keywords are combined using boolean terms such as AND and OR. When an article is found, a preliminary assessment is carried out by reading the introduction and conclusion, before reading the entire paper, if this one is estimated sufficiently relevant to be included. Afterwards, the snowballing technique is employed, both in a backward and frontward manner, by looking at potential articles to read in the cited references of the chosen articles, and in studies that have cited the previously selected articles. The articles selected are then categorised by travel distances, methodologies used and attributes studied.

3.2. Transfers in short and medium distance travels

In this section, the existing literature on transfers on short and medium-distance trips is reviewed. Short-distance trips here refer to daily trips such as commute journeys, usually within the same urban area. Medium-distance trips encompass trips between different cities within a range of up to 150 kilometres in the same country and region. The studies found for these distances are summarised in Table 3.1, showing the year and country of the study, their topic, the modes that have been studied, as well as the type of data collected and the models used to analyse this data.

Most of the studies on transfers on short and medium-distance trips have been focused on the analysis of route choices and trade-offs people make when having to transfer in a multimodal network, as well as the estimation of their transfer penalty, mostly at the urban level.

3.2.1. Short distance trip transfers

Methodologies

Most studies on traveller behaviour on short-distance trips rely on surveys and questionnaires to gather data. The most commonly employed method is Stated Preferences (SP), where participants are asked

Table 3.1: Overview of literature on transfers in short and medium-distance travelling

Author	Year	Country or Region	Topic	Modes	Model	Data Type
Arentze and Molin	2013	The Netherlands	Travelers trade-offs in multimodal route choice	Private vehicle, Public transport	MNL	SP survey
Bovy and Hoogendoorn-Lanser	2005	The Netherlands	Behavior of train travelers in inter-urban multimodal route choice	Rail for main, Other modes for access/egress	HNL, MN-GEV	RP survey
Cascajo et al	2019	Spain	Factors influencing user transfer perception to reduce transfer penalty	Bus, Train	Literature review, Thematic analysis	RP focus group
Ceder et al	2013	NZ	Uncertainty impact on out-of-vehicle time during transfer	Bus, Train, Ferry	Cumulative prospect theory, Fuzzy logic	SP survey
Chowdhury et al	2015	NZ	Trade-offs between time, cost, and willingness to choose a route with transfer	Bus	Just Noticeable Difference	SP survey
de Keiser et al	2015	The Netherlands	Penalty value of time of transfer	Rail	MNL	SP survey
Douglas and Jones	2013	Australia	Estimate travel time penalty	Rail and bus	MNL	SP survey
Eluru et al	2012	Canada	Factors dissuading individuals to commute by public transport	Bus, Metro, Train, Car	MNL, ML	RP survey
Espino	2019	Spain	Willingness of travelers to pay to avoid transfer routes by bus	Bus	ML	SP survey
Guo and Wilson	2004	US	Assessment of perceived cost of transfer by location	Metro	Path choice	RP survey
Guo and Wilson	2011	UK	Assessment of perceived cost of transfer by location	Metro	Path choice	RP survey
Ha et al	2020	South Korea	Impact of travel time, cost, and transit burden on commute mode choice	Car, Transit	Binomial logistic regression	RP survey

to choose between different alternatives to reveal their preferences (Ceder et al., 2013; Chowdhury et al., 2015; Douglas & Jones, 2013; Espino, 2019). For instance Douglas and Jones, 2013 conducted a survey in Sydney, Australia, distributing questionnaires at a train station and bus stops. Participants were asked to make different choices between two journey options, enabling to estimate the penalties travellers associate with different types of transfers per income group. Similarly, Espino, 2019, carried out surveys at various bus stations on the island of Grand Canaria, Spain. Passengers were asked to communicate their preferences between two bus journeys, aiming at determining the travellers' willingness to pay (WTP) to avoid a transfer, depending on the transfer type. In the study by Ceder et al., 2013, surveys were distributed in Auckland, New Zealand at a train station and a hub where transfers between train, bus and ferry are possible, offering choices between three alternatives. Unlike the other studies, this research did not offer choices between modes or journey alternatives but focused solely on different transfer alternatives to assess how uncertainty during transfer and transfer facilities affect travellers' willingness to use a particular route. Another study in Auckland, conducted by (Chowdhury et al., 2015), involved distributing surveys at bus stations. These surveys presented participants with choices between two bus routes, one of which included a transfer, to meet the objective of measuring passengers' perception of transfers.

Less frequently, revealed preference (RP) data was used in travel behaviour on short-distance travels. With this approach, data describing actual trips made by the travellers, though the full set of alternatives available to the travellers is unknown to the researcher (Cascajo et al., 2019; Guo & Wilson, 2004, 2011; Ha et al., 2020). For example, in the study by Ha et al., 2020, data from the Seoul metropolitan area's 2016 Household Travel Survey (HTS) was combined with online route information to measure the impact of transit burden, including transfers, on the mode choice between car and transit. The HTS provides data on the inhabitants' typical weekly trips, including their origin and destination. Similarly, studies by Guo and Wilson, 2004 and Guo and Wilson, 2011 estimated the transfer penalties in the metro networks of Boston in time and London in time and cost respectively. These studies used onboard surveys conducted by the respective transport authorities, with recorded full journey details, including origins and destinations. This data was then combined with Geographic Information System (GIS) data, as it is not possible to see the alternatives that have not been selected with the survey results. In contrast to these researches, the study by Cascajo et al., 2019, conducted in the Spanish cities of Victoria-Gasteiz and Madrid, also employed RP data but qualitative data rather than quantitative data. This was made through focus groups where semi-structured interviews were conducted with small groups of inhabitants. This qualitative data was further combined with a literature review to identify the most important elements influencing the perception of transfers.

To analyse the data collected, different modelling approaches have been used. Discrete choice modelling is used in various forms to analyse travellers' preferences when travelling for shorter distance journeys (Douglas & Jones, 2013; Espino, 2019; Guo & Wilson, 2004, 2011; Ha et al., 2020). (Douglas & Jones, 2013) applied a multinomial logit model (MNL) to the data collected, when (Espino, 2019) employed a mixed logit (ML) model, which is an advanced form of the MNL, incorporating respondents heterogeneity into the analysis. A binomial logistic regression model was utilised by Ha et al., 2020, since the study focused on only two travel mode alternatives. Finally, path choice models were used in Guo and Wilson, 2004 and Guo and Wilson, 2011, with the results being analysed at the station level to understand travellers' route selections.
Other studies employed different quantitative modelling techniques beyond discrete choice models (Cascajo et al., 2019; Ceder et al., 2013; Chowdhury et al., 2015). For example, Ceder et al., 2013 used cumulative prospect theory, which models imprecision in human behaviour, alongside a fuzzy logic model that accounts for the intuitive nature of travellers' decisions. Chowdhury et al., 2015 applied the just noticeable difference (JND) method, which quantifies the perception of the ratio of differences between two alternatives.
For the study involving quantitative data (Cascajo et al., 2019), a different type of methodology was required. A thematic analysis was conducted to interpret the qualitative data collected.

Attribute studied and main findings
The sub-section outlines the key transfer-related attributes studied in the literature, along with the main findings regarding the trade-offs made by travellers and the estimated transfer penalties for short-distance journeys.

In addition to commonly studied attributes in behaviour studies on transportation such as travel time, represented by the total travel time or the in-vehicle travel time, and the travel cost (Chowdhury et al., 2015; Douglas & Jones, 2013; Espino, 2019; Guo & Wilson, 2004, 2011; Ha et al., 2020), various transfer-related attributes have been studied in the literature found. The attributes studied are summarised in Table 3.2.
Firstly, the effect of the number of transfers on traveller choices was examined in two studies (Guo & Wilson, 2011; Ha et al., 2020). While the number of transfers is unspecified in Guo and Wilson, 2011 research, it is categorised between one transfer and more than 1 transfer in comparison to no transfer in Ha et al., 2020.
Operational aspects of a transfer were more extensively studied with more than half of the studies focusing on the walking time between platforms and the waiting time at transfers (Ceder et al., 2013; Douglas & Jones, 2013; Guo & Wilson, 2004, 2011). Waiting and walking time were identified as major contributors to transfer penalties in the quantitative study of (Cascajo et al., 2019). In some cases, the walking distance was considered instead of walking time (Guo & Wilson, 2011; Ha et al., 2020). Furthermore, the impact of transfer time on travellers' preferences and the frequency of the second travel leg, expressed in time in minutes between two buses, were also assessed in Espino, 2019. Finally, in Ceder et al., 2013, the service reliability impact is explored, as a delay at transfer.
Beyond attributes related to service and performance, the transfer penalty differences related to the type of transfer have been investigated in research (Douglas & Jones, 2013; Guo & Wilson, 2004, 2011). For example, Douglas and Jones, 2013 estimated the penalty differences for travellers for transfers between rail and bus and bus and bus at an interchange, but also between rail and rail at the same and different platforms. On the other hand, in Guo and Wilson, 2011 and Guo and Wilson, 2004, the penalties are assessed according to whether the transfer is at the same level or a different level using assisted level change such as stairs or escalator. Additionally, the ramp length when changing platform is included in the study of Guo and Wilson, 2011.
The transfer-related characteristics concerning the transfer points like train stations were also studied with a focus on the comfort while waiting (Ceder et al., 2013; Chowdhury et al., 2015), such as the availability of seating, shelter and food availability. Additionally, safety perceptions when waiting for transfer were considered by Ceder et al., 2013 while the availability of transfer information at stations

emerged as a prominent concern among focus group participants in the study by Cascajo et al., 2019.

Table 3.2: Overview of transfer-related attributes studied in short-distance travel behaviour literature

	Cascajo et al., 2019	*Ceder et al., 2013*	*Chowdhury et al., 2015*	*Douglas and Jones, 2013*	*Espino, 2019*	*Guo and Wilson, 2004*	*Guo and Wilson, 2011*	*Ha et al., 2020*
Walking time	**X**	**X**		**X**		**X**	**X**	
Walking distance							**X**	**X**
Waiting time	**X**	**X**		**X**		**X**	**X**	
Transfer type				**X**	**X**	**X**	**X**	
Number of transfers							**X**	**X**
Frequency					**X**			
Delay at transfer		**X**						
Comfort		**X**	**X**					
Ramp length							**X**	
Availability info.	**X**							
Safety perception		**X**						

Results from the studies show that dispreference for transfers has been commonly observed, mostly through equivalent time and cost penalties. This aversion intensifies with the increase of transfers and variate per mode of transport.
The study by Ceder et al., 2013, which concerned specifically transfer-related characteristics, found that passengers penalise out-of-vehicle time more heavily than in-vehicle time. Travellers exhibited a clear preference for routes with less uncertainty during out-of-vehicle time, suggesting that reducing this uncertainty could enhance the attractiveness of routes involving transfers and boost public transport usage. Similar findings are reported by Espino, 2019, which revealed than an additional minute of waiting time between two busses is perceived as having a higher disutility than an extra minute of travel time. Furthermore, Douglas and Jones, 2013 found that transfer time, a combination of walking time and waiting time, is valued 10% more than in-vehicle time. The penalty changes were found to be negligible when considering the respondents' income. In Guo and Wilson, 2004 and Guo and Wilson, 2011, transfer penalty in terms of equivalent in-vehicle time was estimated for the Boston and London metro systems respectively. In Boston, transfer penalties ranged from 3.5 to 31.8 minutes, while in London, they ranged from 0.5 to 9 minutes. Variations in penalties were observed depending on the station, with lower penalties associated with escalators, longer ramps, and same-level transfers, as well as during off-peak periods. The study conducted by Douglas and Jones, 2013 in Sydney, the penalties were estimated based on the type of transfer. Rail-to-rail cross-platform transfers were found to be associated with the smallest penalty, with 12.5 and 7 minutes, for bus and train users respectively, which is 2.4 minutes less than rail-to-rail up and down cross-platform, for train users only. The penalty was found to be 14.5 minutes and 23 minutes for bus-to-bus transfer for bus users and rail users, and 15 minutes and 17.5 minutes for rail-to-bus transfer for bus and train users. An overview of the different transfer penalties in terms of in-vehicle time in minutes is provided in Table 3.3. For the transfer penalty cost, it was found that travellers are willing to pay 0.33€ to avoid a transfer when travelling by bus in an urban context (Espino, 2019).

For the impact of transfer(s) on mode choice, research conducted in the Seoul metropolitan area revealed that the likelihood of car use increased by 4.7% for scenarios involving one transfer and by 24.3% for those with multiple transfers (Ha et al., 2020). For middle-income groups and individuals un-

Table 3.3: Overview of the transfer time penalty for different transfer types in short-distance travelling

	Guo and Wilson, 2004	*Guo and Wilson, 2011*	*Douglas and Jones, 2013*			
Location	**Boston**	**London**	**Sydney**			
Transfer type	**Metro-metro**	**Metro-metro**	**Rail-rail (cross-platform)**	**Rail-rail (up and down)**	**Bus-bus**	**Rail-bus**
Transfer penalty (in minutes)	3.5 to 31.8	0.5 to 9	9.8	13.7	18.8	16.3

der 35, car use increased by more than 30% when transfers were involved in the journey. An increase in the walking distance during a transfer was also found to increase the dispreference for transfer. In Ha et al., 2020, an additional 100 meters in walking distance was found to lead to the raise of the car use probability by almost 5%. A summary of the findings of the impact of transfers on car use is shown in Table 3.4.

Table 3.4: Overview of the impact of transit transfer on car use (Ha et al., 2020)

Transit	**1 transfer**	**2+ transfers**	**2+ transfers (35yo+)**	**+100 meters walking**
Car use	+4,7%	+24,3%	+30%	+5%

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To finish, results on the value given to comfort at transfer points are described. In the research by Chowdhury et al., 2015 in New Zealand, the main findings revealed that for basic comfort amenities at transfers, respondents desired a 33% reduction in travel time and a 16% reduction in travel cost in comparison to direct routes, while enhanced comfort amenities prompted a desire for a 25% reduction in travel time and a 10% reduction in travel cost. Furthermore, 43% of respondents were unwilling to sacrifice time savings for more comfortable transfers and 28% of respondents were unwilling to sacrifice cost savings for more comfort at transfers. If the travellers were willing to decrease gain in travel time and travel cost for comfort improvement at transfer points, it was found to be between 5 and 15 minutes for travel time and around 2$NZD for travel cost. This shows that travellers are more sensitive to travel time than travel cost.

3.2.2. Medium distance trip transfers

A study conducted in the Netherlands focused on train users along a 150 km corridor (Bovy & Hoogendoorn-Lanser, 2005). It utilized the HNL and MN-GEV models to estimate trade-offs made by travelers using revealed preferences data collected on trains. The study examined various modes used for access and egress to the main train mode. Attributes related to transfers, such as walking time, waiting time, and service frequency, were evaluated. It was found that a higher frequency of the connecting train significantly reduced disutility, equivalent to a 5-minute penalty in in-vehicle time compared to a lower frequency, which had an equivalent penalty of 10 minutes in in-vehicle time.
In another study from the Netherlands (Arentze & Molin, 2013) , an MNL model was applied to stated preferences data gathered via an online questionnaire. This study focused on combinations of private vehicle and public transport modes over various distances. It analyzed multiple contexts including trip purpose, travel party, and weather. Transfer-related attributes such as transfer versus direct train, transfer time, reliability, and station facilities were estimated. The study highlighted that transfers occurring during the main stage of a trip had a notably negative impact. Additionally, for distances exceeding 65 kilometers, a 10-minute railway transfer was equivalent to 22 minutes of in-vehicle time, suggesting a transfer penalty of 12 minutes.
In the Netherlands, de Keizer et al., 2015 quantified the penalty value of time associated with intercity train transfers. This study focused specifically on intercity train transfers using two experimental setups—one with a single interchange and another with two different interchanges. Attributes evaluated included punctuality, transfer time, frequency of the connecting train, transfer type (cross-platform, cross-station, with/without lift), and number of transfers. Results indicated that a railway transfer penalty amounted to 23 minutes under conditions involving a 2-minute transfer time with a cross-platform trans-

fer and an additional waiting time of 15 minutes due to service frequency. The study also identified non-linear preferences for transfer time, with disutility decreasing between 2 and 5 minutes and increasing beyond 5 minutes. Moreover, a 1-minute transfer time was equivalent to 1.67 minutes of travel time, with cross-station transfers incurring an additional 7.22 minutes compared to cross-platform transfers. For travelers with luggage, penalties ranged from 6.4 minutes for no luggage to 13 minutes for heavy luggage.
In the study conducted in Spain (Espino, 2019) focusing on willingness to pay (WTP) to avoid transfers, particularly for buses in both urban and non-urban settings, it was found that for non-urban transfers, travelers expressed a higher WTP (0.56€) compared to urban transfers, indicating varying preferences and perceived inconveniences associated with transfers in different contexts.

3.3. Transfers in long-distance travels

In this section, the literature found on traveller behaviour for transfers in long-distance international travel is described. An overview of the studies reviewed is presented in Table 3.5.

Table 3.5: Overview of literature on transfers in long distance travelling

Author	Year	Country or region	Topic	Modes	Model	Data type
Adler et al	2005	US	Passengers service trade-offs	Plane	Logit ML	RP-SP survey
Coldren et al	2003	US	Service attributes influencing itinerary choice	Plane	MNL	RP data
de Barros et al	2007	Sri Lanka	Factors influencing transfers' passengers LOS at airports	Plane	Regression	SP survey
Hae Choi et al	2019	SE Asia- N America	Parameters influencing transfer airport choice	Plane	Two-stage least square	RP survey
Herring et al	2019	US	Airline customers' connection time preferences	Plane	MNL	RP data
Hess	2008	US	Forecast passenger demand	Plane	MNL	SP survey
Hess et al	2006	US	Airport and airline choice	Plane	MNL	RP-SP survey
Johnson et al	2014	Scotland	Trade-offs between access conditions to airports and connecting flights	Plane	Cross-Nested Logit	SP survey
Landau et al	2016	US	VOT of airline passenger attributes to each trip component	Plane	MNL	SP survey
Lu et al	2021	China	Hesitancy in transfer airport choice	Plane	MNL Random forests algorithm Deep reinforcement learning	RP-SP survey
Morlotti et al	2023	Italy	Itinerary choice considering LOS and connection quality attributes	Plane	Exploratory factor analysis Latent class choice	SP survey
Theis et al	2006	US	Impact of transfer time on itinerary choice	Plane	MNL	SP survey
Warburg et al	2006	US	Service attributes impact on air itinerary choice	Plane	MNL ML	RP-SP survey

In the studies on transport behaviour for long-distance travel, the current body of research primarily focuses on plane transfers, with studies mainly related to airport choice (Choi et al., 2019; Hess, 2008; Hess et al., 2007; Johnson et al., 2014; Lu et al., 2021) or route choice, also referred as itinerary choice in these studies (Adler et al., 2005; Coldren et al., 2003; Herring et al., 2019; Hess et al., 2007; Morlotti et al., 2023; Theis et al., 2006; Warburg, 2006). In studies on airport choice, the focus is made on the airport characteristics to improve to attract passengers and incite them to use a specific airport for their transfer. Researches on route choice explore the trade-offs travellers make between direct routes or routes involving transfers, considering parameters such as total travel time and travel costs. Furthermore, research around plane transfers has been mainly located in the United States.

Methodologies

Most studies on transfers in long-distance travel rely on stated preferences data collected through surveys, either on their own (de Barros et al., 2007; Morlotti et al., 2023) or, more frequently, combined with revealed preferences data (Adler et al., 2005; Hess, 2008; Hess et al., 2007; Johnson et al., 2014; Lu et al., 2021; Theis et al., 2006; Warburg, 2006).
In Morlotti et al., 2023, a stated preference survey conducted in northern of Italy presented respondents with three travel alternatives, one direct and two involving transfers, each with different airport service levels and connection characteristics. Similarly, de Barros et al., 2007, studied trade-offs between ser-

vice levels and transfer characteristics through a survey at an international airport in Sri Lanka, where participants ranked airport facilities and services.
In the study by Theis et al., 2006, the results of an online annual airline survey in the US, the Ressource Systems Group (RSG) survey are used. In this survey, travellers chose between their usual itinerary involving a transfer and a hypothetical alternative, to assess the impact of transfer time on demand. This same survey was also used in the studies by Hess et al., 2007and Hess, 2008. Similarly in Johnson et al., 2014, revealed and stated preferences are combined for the data collection. Travellers are asked in the questionnaire to choose between two alternative trips in Scotland, their usual trip and a hypothetical alternative, to estimate the trade-offs made between the access conditions to the airport and the connecting flight characteristics. In Adler et al., 2005, Warburg, 2006 and Lu et al., 2021, respondents were also asked to make choices between their last trip made and a hypothetical option, to study the influence of the level of service on itinerary choice (Adler et al., 2005; Warburg, 2006) and the impact of hesitancy on transfer airport choice (Lu et al., 2021).
Less frequently, studies have relied solely on revealed preference data, collected either through surveys (Choi et al., 2019) or direct data collection methods such as ticket purchase records (Coldren et al., 2003; Herring et al., 2019). In Choi et al., 2019 an Airport Serving quality (ASG) survey is used to assess factors influencing passengers' transfer airport choices. In the study by Coldren et al., 2003, data collected via a Computer Reservation System is analysed to investigate how airport service attributes affect travellers' itinerary choices. Similarly, in Herring et al., 2019, ticket purchase data is processed to model travellers' preferences for short or long connections.

To analyse traveller behaviour, most studies applied discrete choice modelling. The Multinomial Logit model (MNL) is the most commonly used (Coldren et al., 2003; Herring et al., 2019; Hess, 2008; Hess et al., 2007; Landau et al., 2016; Lu et al., 2021; Theis et al., 2006). However, other types of discrete choice models are employed as well, such as the Mixed Logit model (ML) (Adler et al., 2005; Warburg, 2006), the latent class choice model (LCMM) (Morlotti et al., 2023) and the Cross*nested logit model (Johnson et al., 2014). Some studies incorporate alternative modelling approaches, such as Lu et al., 2021 which used a Random Forest algorithm and deep reinforcement learning alongside MNL to study hesitancy in airport choice. Regression models are also occasionally used (Choi et al., 2019; de Barros et al., 2007), but less frequently.

Attribute studied and main findings
In the sub-section, a summary of the attributes examined in the various studies on long-distance travel transfers and a highlight of the main findings on travellers' preferences are given. In addition to more traditional attributes used in discrete choice modelling such as travel time and travel costs; diverse transfer-related attribute types are studied in literature to illustrate the impact of transfers.
The current body of literature mainly focuses on the study of the behaviour of travellers according to the type of route (Hess, 2008, Theis et al, 2006, Herring et al, 2019) and the number of transfers, also called connections (Coldren et al, 2003, Morlotti et al, 2023, Warburg et al, 2006). When the type of route is considered, non-stop flights and direct flights, that can stop to take passengers, are differentiated, next to flights with connections.
Different attributes related to transfer time were also considered in the studies, such as the transfer or connection time (Adler et al., 2005; Johnson et al., 2014; Theis et al., 2006), the minimum connection time (MCT) (Choi et al., 2019; Johnson et al., 2014; Theis et al., 2006) and the buffer time (Herring et al., 2019; Landau et al., 2016; Theis et al., 2006). The transfer time is defined as the time between the first plane's arrival and the departure of the next one. The MCT is defined as the minimum time a passenger will need to transfer successfully, including, for example, the walking time. Lastly, the buffer time is the difference between the transfer time and the MCT, so the traveller's extra time to conduct activities during their transfer, such as buying food, using the toilets, or just walking with less stress to the gate of the next plane.
Some other attributes are studied more scarcely, such as the service quality of the transfer airport, such as the services offered (Choi et al., 2019; Coldren et al., 2003) or the detour factor, seen as the distance difference between the flight with transfer and the direct flight (Choi et al., 2019). An overview of the different attributes studied in the literature on long-distance travelling is given in Table 3.6.

A preference for direct flight and avoiding connections is the main behaviour observed in the majority

Table 3.6: Overview of transfer-related attributes studied in long-distance travel behaviour literature

	Adler et al., 2005	Coldren et al., 2003	de Barros et al., 2007	Choi et al., 2019	Herring et al., 2019	Hess, 2008	Hess et al., 2007	Johnson et al., 2014	Landau et al., 2016	Lu et al., 2021	Morlotti et al., 2023	Morlotti et al., 2023	Warburg, 2006
Number of transfers	X				X	X	X						X
Transfer time								X		X		X	
MCT				X	X							X	
Buffer time		X			X				X			X	
Service quality		X	X	X						X			
Detour factor				X									
Anxiety											X		

of the studies on itinerary choice in plane travelling (Coldren et al., 2003; Herring et al., 2019; Hess, 2008; Johnson et al., 2014; Theis et al., 2006). The travellers are looking into avoiding connections as when there is a transfer, they perceive as negative the increase in travel time as well as the inconvenience of switching planes, the increase in the probability of high delays and the potential loss of luggage (Coldren et al., 2003). Furthermore, there is a double negativity in some studies for connection, as they can be included in different attributes of the utility, such as the travel time and the travel performance (Adler et al., 2005). It was found that travellers are willing to pay relatively high prices to ensure a direct flight. These costs vary according to the type of travellers, the data collection type and the type of model used to estimate the weight of the attributes in the decision process. Some travellers would travel to further airports than their proximity airport and increase their access time to airports, to have a direct flight and avoid any transfer (Coldren et al., 2003; Hess, 2008; Johnson et al., 2014). In the US study of Hess, 2008, it is found that travellers are willing to pay around 40$ more in the SP survey and around 59$ more in the RP survey to have a direct flight, which is more than the WTP for a departure from the closest airport, which is valued around 21$ for SP survey and around 39$ for RP collected data. Similarly, in the study by Theis et al., 2006, travellers were found to have a WTP of 58$ to avoid a connection. This WTP to avoid transfers was also found to vary according to the trip purpose of the travellers, with business travellers willing to pay 44$ to avoid a connection, while holiday travellers are willing to pay 20$ to avoid a connection. However, the WTP stays the same for business travellers to avoid two transfers when the WTP of leisure travellers is increasing to 62$ (Hess, 2008). In the study by Warburg, 2006, the WTP for direct flights was found to be higher when only business travellers were considered, with a value of around 76$. Even higher values were found in Morlotti et al., 2023, where the WTP for a direct flight was found to be around 82€ for the average of the three classes found in the LCMM model and approximately 78€ for the ML model. In this same study, it was found that the WTP for direct flights was higher for more anxious people. The dispreference for transfer is also expressed in cost loss instead of WTP. In Adler et al., 2005, a connection is associated with a loss of 54$ for business travellers and 19$ for leisure travellers. These results, all converted in euros, are summarised in Table..., taking into account their main characteristic a difference was observed for example the trip purpose or the type of model used.

Table 3.7: Willingness to pay to avoid a plane transfer per location and main study characteristic

	Hess, 2008				*Theis, 2006*	*Warburg, 2006*	*Adler, 2005*		*Morlotti, 2023*	
Location	**US**				**US**	**US**	**US**		**Italy**	
Characteristic	**SP**	**RP**	**Work (SP)**	**Leisure (SP)**	**-**	**Work**	**Work**	**Leisure**	**LCMM**	**ML**
WTP or loss (€)	36	54	40	18	53	69	49	17	82	78

The estimation of the utility and disutility associated with the transfer time, connection time and buffer time led to different results in the literature. Furthermore, in these studies, these different times are perceived as non-linear in their contribution to the utility of travellers (Coldren et al., 2003; Herring et al., 2019; Johnson et al., 2014; Landau et al., 2016; Theis et al., 2006). In Landau et al., 2016, a buffer time close to 15 minutes is seen as positive by travellers but this perception became negative when the buffer time became higher than 15 minutes. In Coldren et al., 2003, travellers are also seen as preferring a shorter ground time in case of connection. Similarly, in Theis et al., 2006, buffer times inferior to 6 minutes and superior to 15 minutes are associated with disutility, when a buffer time between these two values contributes to the increase of the utility. In Herring et al., 2019, 25 minutes is considered as the ideal buffer time, from which the utility of the buffer time starts to decrease, which is 10 minutes more than the other studies. With the connection time, the preferred values were found to be higher, with 60 and 90 minutes considered as ideal and 45 minutes and 120 minutes found as bringing disutilities to the travellers (Johnson et al., 2014). This preference for higher connection time is opposite to the study by Choi et al., 2019, where an increase in the market share of an airport is found to increase approximately 5% each 10-minute decrease of MCT. Such results can be explained by the trade-offs travellers are making between the connection time and the time they can allocate to diverse activities during their transfer (Landau et al, 2016).
A larger detour degree is also seen has been associated with a smaller market share for the transfer airport (Hae Choi et al, 2019). Hesitant people and choice in ground transfer attributes (service quality related) are seen as more important than airlines-related attributes, in the transfer airport choice (Lu et al, 2021). The willingness to pay was also considered for other attributes, such as the MCT, detour degree and service level. In the study by Choi et al., 2019, WTP values were determined for various improvements in travel conditions. Participants indicated a WTP of 80$ for a reduction of 10 minutes in minimum connection time (MCT), 93$ for a decrease of 0.1 in detour degree, and 94$ for an increase of 0.1 in service level.

3.4. Conclusion and main takeaways

The literature on traveller behaviour regarding transfers primarily focuses on long-distance plane transfers and multimodal commuting, which often includes urban or short-distance railway travel. These studies typically employ discrete choice models, primarily multinomial logit (MNL), and utilise stated preference (SP) surveys to gather input data.
Transfer penalties in these studies are commonly assessed in terms of in-vehicle time or equivalent costs. Key attributes such as waiting time, walking time, transfer time, number of transfers, and reliability are extensively studied for their impact on travel decisions. Contextual factors, such as trip purpose, significantly influence how travellers perceive these transfer penalties.
Studies consistently reveal a strong preference for direct travel over connections due to concerns such as extended travel times, potential delays, and the inconvenience of changing mode. This preference is particularly pronounced among travellers with higher anxiety levels (Choi et al., 2019). Transfer time emerges as a critical factor influencing traveller decisions, encompassing parameters like connection time, minimum connection time (MCT), and buffer time, especially in plane literature. Research indicates that travellers view transfer time positively up to a certain threshold, beyond which the utility start to decline (Landau et al., 2016; Theis et al., 2006).
Regarding willingness to pay (WTP), travellers demonstrate a significant financial commitment to avoid transfers and secure more favourable travel conditions. Studies indicate WTP values ranging from 20$ to 82 to avoid connections, varying with trip purpose and anxiety levels (Hess et al., 2007; Morlotti et al., 2023). Travellers are also willing to pay more for improvements in transfer-related characteristics.
This literature review revealed a significant gap in research on traveller behaviour concerning railway transfers during long-distance journeys in Europe. Given that the literature shows transfer penalties vary depending on the type of transfer and trip distance, it is crucial to study the impact of transfers in this specific context.

4 Methodology

In this chapter, the methodology used to answer the research questions and complete the objective of the research is presented. In section 4.1 the interview conception and the thematic analysis used to analyse the answers obtained from the interviews are described. In section 4.2, the choice experiment that will be applied is justified. Finally, in section 4.3, the methodologies of discrete choice modelling and of the model that will be used in the study are explained and the application of the results are computed in Section 4.4.

4.1. Interviews

4.1.1. Data collection

Interviews are conducted to gain more insights into the behaviour of long-distance travellers in relation to railway transfers and contribute to answering the sub-research question 1. A document with the different questions that would be asked to the travellers is first prepared, including questions reflecting the traveller's frequency in travelling internationally specifically in Europe, modal preferences, experience with railway transfers, and more importantly, elements travellers find important in railway transfers. To gather opinions of people more likely to have experienced international travelling in Europe, travellers are interviewed at main train stations in the Netherlands, where it is possible to travel internationally by train and/ or plane, such as Rotterdam Centraal and Amsterdam Schipol. The questions asked are based on the document and adapted according to the participant's answers, as well as the time they can dedicate to answer to the questions. The answers are noted by hand.

4.1.2. Thematic analysis

The data obtained from the interviews is analysed using the thematic analysis method. The output of this analysis constitutes the elements considered important by the respondents in railway transfers, thus helping to form a list of important transfer-related attributes for long-distance travellers. These insights will be used to address the sub-research question 1. Thematic analysis is a method used to analyse qualitative data and is here applied to the transcript results of interviews. It identifies common themes and patterns within the transcript by highlighting repeated words or meanings. This method can be applied in 6 distinct steps (Caulfield, 2019). In the initial step, the researcher is getting familiar with the data. In the second step, different sections of the data are highlighted, and the selected text is described by labels or "codes", providing a first idea about the key points of the data and the main opinion of people interviewed. In the following step, the themes are generated by combining similar codes. The fourth step involves reviewing the different themes extracted from the data to ensure the correct representation of the data. Then, these themes are defined and named. Finally, the sixth step consists of writing the analysis of the data. The identified themes in this study will correspond to the attributes and different contexts. This thematic analysis is being realised using the ATLAS.ti software, conceived to facilitate the treatment and analysis of qualitative data.

4.2. Choice experiment

To address sub-questions 2 and 3, data on travellers' preferences needs to be collected and analysed. This study seeks to identify the elements passengers find the most crucial in train transfers and their mode preferences between trains with transfer and direct mode alternatives. To do so, find the trade-offs travellers make between different aspects of a railway transfer and their trip is necessary.

4.2.1. Data collection method

Directly asking people for their trade-offs is impossible as they are usually unaware of the trade-offs they make in their decision-making process (Chorus, 2021). Because of this impossibility, a choice experiment needs to be implemented. In a choice experiment, the choices made by the travellers are analysed. Through this analysis, it is possible to estimate the importance or weights given by the travellers to the different characteristics, known as attributes, of the alternatives presented to them. This analysis allows to see the specific characteristics that influence people's decision-making and to what extent (ChoiceMetrics, 2024).
Two main data types can be used for choice experiments: revealed preferences (RP) and stated preferences (SP) data. These two types of data, as well as their advantages and limitations, are described below.

Revealed preferences (RP)
Revealed preference data can be obtained through existing data, direct observation or surveys designed to collect information directly from the travellers about their past transportation experiences. In surveys, revealed preferences capture data reflecting the travellers' actual behaviour, considering available options. This approach provides access to accurate data on travelling choices (Train, 2009). However, revealed preferences have limitations as certain attributes could be challenging to include in the survey and to measure if they do not exist in real life. Furthermore, this type of data enables the observation of the mode choices but limits insights into the traveller's behaviour and the trade-offs they considered in their choices, as the alternatives considered by the traveller are unknown (Molin,2021).

Stated preferences (SP)
Stated preference data is gathered through stated preference surveys and are "based on individuals' stated behaviour in hypothetical scenarios" (Román et al., 2007). Through the possibility of including both existing and non-existing alternatives in the choice set, SP surveys offer the opportunity to, for example, forecast future demand for different transport modes and assess the impact of various attributes and parameters on travel behaviour. Furthermore, it is possible to find the underlying reasons behind those choices and analyse the trade-offs passengers make in their decision-making process (Molin, 2021). However, stated preference surveys have drawbacks. Responses provided by the traveller could be not fully aligned with the choices they would make in real-life situations (Molin, 2021). The differences between the choices they would make in reality and what they are stating when answering the survey could be due to bias introduced in the survey during its elaboration (Wardman, 2001).

In this study, a stated preferences survey will be used to present hypothetical travel alternatives in the choice set to the participants. This approach makes possible the estimation of the parameters of attributes and attribute levels that may not exist in real life. Additionally, making use of SP surveys offers the advantage of reducing the required sample size compared to RP surveys, as highlighted by Ortúzar and Simonetti, 2008. For instance, in Germany in 2008, individuals made, on average, 1 or 2 long-distance trips during the year (Aamaas et al., 2013). An RP survey would result in only 1 or 2 choice data points per respondent. However, in SP surveys, respondents have the opportunity to make multiple choices, thus generating a greater volume of usable data, even with a smaller sample size.

4.2.2. Choice experiment design

In this sub-section, a description of the methodological choices that need to be made to design a stated preferences survey is given. Each choice set in the survey is composed of alternatives, here different transport options for a same route. Each of these alternatives is defined by different attributes, which are their characteristics and that can take different values, called attribute levels. Careful selection of the attributes and their levels need to be done, to correctly capture respondents' preferences (ChoiceMetrics, 2024). The selection process will be defined in this section, as well as the experimental designs.

Attributes selection
The attributes selection should be based on their perceived importance to travellers and their potential relevance in influencing related policies (Molin, 2021). In this research, the attributes will be defined by combining the existing literature on transfers across different modes and distances with the previous interview results. To maintain survey effectiveness, the number of attributes should be limited to the most relevant ones. This will prevent overloading respondents with excessive information and mitigate the risk of survey fatigue. Such fatigue could result in respondents limiting their trade-offs between a few attributes or randomly selecting alternatives.

Attribute levels selection
The number of levels of the attributes typically falls within the range of two to four (Molin, 2018). Determining the appropriate number of levels for each attribute requires considering different factors. For the minimum number of levels, the expected shape of the utility function of the attribute should be considered. If the utility function is expected to be linear, two levels may be enough. However, if the utility function of an attribute is expected to be non-linear, at least three levels will need to be defined for the attribute, as it will not be possible to test for non-linearity with only two levels. If the utility function of an attribute is expected to take a S-shape, four levels will be required for this attribute. Furthermore, for categorical attributes, it is important to consider any relevant category (ChoiceMetrics, 2024). The final choice on the number of attribute levels will depend on the degree of precision expected for the trade-offs in the analysis. Furthermore, the different attributes should not have too many different numbers of levels. For example, having attributes with two, three and four levels in the same experiment should be avoided, as it will require more computation and a larger choice set. In this study, the attributes will have two or four levels.
The values assigned to the attribute levels should span a broad range to take into account all types of values that these attributes could take in reality, allowing to increase both the validity and the reliability of the survey. Additionally, maintaining equidistance between the levels is important to preserve orthogonality between the attribute levels (Molin, 2018).

Number of rows selection
The number of choices offered to the respondents, also called “rows” in the Ngene software that will be used for the design, depends on different parameters, such as the number of attributes, the number of levels of these attributes as well as the interactions between the different attributes' levels. The number of choices needs to be enough and have sufficient variation to allow a reliable estimation of the parameters of the attributes. The number of rows should also be enough to account for possible interactions between the attributes. However, this number should also be limited, to not exhaust the respondents. If the number of rows is too important for one choice set, blocks can be added in the design to divide the choice set into blocks of sub-choice sets.

Experimental design selection
When the attribute and attribute levels have been chosen, they can be combined into alternatives, themselves combined into choices to compose the choice set of the survey. Different types of experimental design can be used to do so, such as full factorial and fractional factorial designs.

Full factorial designs
In this design type, all the possible choices between alternatives are present. This means that all the attribute level combinations and all the effects are represented, including both mains and interaction effects. This design type leads to large choice sets (Molin,2008; ChoiceMetrics, 2024). For this reason, they are only possible to use with a limited number of attributes and attribute levels .

Fractional factorial designs

In this design type, only a fraction of the possible choices from the full factorial designs are selected, leading to the need for fewer choices in the choice set (Molin, 2018). This sub-set of choices needs to be selected in a way that the most reliable data possible from the choice set can be obtained (ChoiceMetrics, 2024). In transportation, usually no interaction effects are observed, so there is no need to optimise them all. If any particular interaction between attributes needs to be minimised, it can be added to the utility specification. Different sub-types of fractional factorial designs exist. The most used is the fractional factorial orthogonal design. In an orthogonal design, the correlations between the attribute levels are minimised. Furthermore, the attribute levels are balanced, which means that all the attribute levels are equally represented, and all the parameters can be estimated independently (ChoiceMetrics, 2024). Another type of fractional design is the efficient design, where the standard errors of the future estimated parameters are minimised. In an efficient design, priors estimated values of the attribute parameters, found in previous research, are required (ChoiceMetrics, 2024).

For the scope of this research, no priors were found in the literature for transfers between two trains for long-distance international travel. For this reason, a fractional factorial orthogonal design will then be generated.

Questionnaire construction
The survey questionnaire, including the choice set and the socio-economic questions will be implemented using Qualtrics, a survey software.

4.3. Discrete choice modelling

In this section, the theory surrounding discrete choice modelling is discussed. To reach the main goal of this research to learn more about travel preferences related to railway transfers for long-distance travel, discrete choice modelling is applied to the previously collected data, as it allows analysis and prediction of travel behaviour (Ben-Akiva and Berliaire, 2013; Train, 2009). The most used theory in discrete choice modelling, the Random Utility Theory (Ben-Akiva and Berliaire, 2013; Train, 2009) will be applied in this research.

4.3.1. Random Utility Maximization (RUM)

In discrete choice modelling, the respondents are assumed to follow a decision rule when making decisions. Within the RUM, the respondents are assumed to maximise their utility by choosing the alternative with the highest utility to them when making a choice. The utility can represent the potential costs and benefits that an alternative will bring to the individual making the decision. This is based on the assumption that people act rationally and have well-defined preferences.
The utility associated from an individual *n* to a certain alternative *i* from their finite choice set C_n is given in the equation 4.1.

$$U_i = V_i + \epsilon_i \tag{4.1}$$

where V_i is the systematic part of the utility and ϵ_i the random part. ϵ_i is representing the unobserved part of the utility that is not captured in V_i .
V_i, the observed part, is defined by the combination of the attributes x_i of the alternative and of their weights β_k on the utility, as shown in equation 4.2. These weights are the parameters that will be estimated in the research.

$$V_i = \sum \beta_k * x_k \tag{4.2}$$

These parameters β will be estimated using the package PandasBiogeme (Bierlaire, 2003), as described in the next sub-section.

4.3.2. Models specification

Different discrete choice models can be applied to estimate the parameters β of the attributes. In this research, two different models will be used: the Multinomial logit model (MNL) and the panel Mixed logit model (ML). A comparison of these models, their strengths and limitations will be given in the rest of this sub-section.

Multinomial logit model

The Multinomial logit model (MNL) is the simplest and most popular model used in discrete choice modelling (Martin and Nombela, 2007; Train, 2009). The main assumption behind this model is that the error term is independently and identically distributed (i.d.d) along alternatives, choices and respondents (Ben-Akiva and Berliaire, 2013). This means that the variance of the unobserved utility is assumed to be the same along the alternatives and the alternatives and choices made are assumed to be uncorrelated. The choice probability equation resulting from this model of an individual *n*choosing alternative *i* is given in Equation 4.3.

$$P_{in} = \frac{e^{V_{in}}}{\sum_{j=1}^{J} e^{V_{jn}}} \tag{4.3}$$

However, the i.i.d assumption is leading to limitations of the MNL model. One of the limitations of the MNL is that it does not account for a possible nesting effect between the alternatives. Furthermore, the MNL model does not account for panel effect. It assumes that all the choices are made by different individuals, and does not consider possible preferences heterogeneity among individuals (Ben-Akiva and Berliaire, 2013). Despite these limitations, the MNL is one of the easiest models and takes less computational time. It is a good starting point for the parameters estimations and will be used as a base model.

Mixed logit model

The mixed logit model (ML) is a highly flexible model that can be applied to all random utility models (McFadden and Train, 2003). Different forms of the ML model exist, such as the panel model which accounts for panel effects and the random coefficient model which accounts for nesting effect. In the panel model, correlations are made between the choices made by the same respondent, while the MNL model considers all choices to be made by different respondents. This is made possible by the ML model using simulation, allowing a variation of the variables among the respondents. This allows to account for the heterogeneity among the respondents, which better reflects real-life decision processes. In the random coefficient model, the correlations between alternatives within a choice are captured through an additional error term. It is possible to observe some drawbacks in the ML model, such as the additional computation difficulty in comparison to MNL model, as well as the requirement of more data that MNL models to have concluding results.

4.3.3. Goodness of fit

After their application, the models' performance needs to be assessed, to see how well the model is fitting the data it is applied to. For discrete choice models, the most commonly used statistical test for goodness of fit is the likelihood index ratio (Train, 2009), also called McFadden's rho-square. In this test, the estimated model is compared to a model where the parameters are fixed to 0. The likelihood index ratio is given by the following formula:

$$\rho^2 = 1 - \frac{LL(\beta)}{LL(0)} \tag{4.4}$$

where *LL(β)* is the log-likelihood of the estimated model, called final log-likelihood, and *LL(0)* is the log-likelihood of the base model, called null log-likelihood. The closer the value of the ratio is from 1, the higher the fit of the estimated to the data is, the value 1 being a perfect fit, which means that the parameters that have been estimated perfectly predict the choices made by the participants (Train, 2009).

The likelihood index ratio does however not account for the number of parameter differences in the model and can be overestimated or underestimated if there are more parameters in one of the models.

The adjusted equation taking into account the number of parameters estimated is given here:

$$adjusted\rho^2 = 1 - \frac{LL(\beta) - K}{LL(0)} \tag{4.5}$$

with *K* being the number of parameters estimated. As for the likelihood index ratio, a value close to 1 is showing a better fit of the model to the data.

The previously given statistical test can be used in the comparison between a base model and the estimated model. If two estimated models need to be compared, different statistical tests need to be performed. In this study, the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC) will be additionally used to assess the performance of the models. They are used to balance the complexity of the model with its goodness of fit, the BIC penalizing more strongly the number of parameters than the AIC. The equation of these statistical tests is given in Equation 4.6 and 4.7 respectively, where LL is the log-likelihood of the estimated model, *K* the number of parameters of this model and N the number of observations. For these two tests, lower values mean a better model performance.

$$\text{AIC} = -2LL + 2K \tag{4.6}$$

$$\text{BIC} = -2LL + Kln(N) \tag{4.7}$$

4.4. Model application

After the computation of the discrete choice models, indicators will be calculated using the attributes parameters values as input. The calculation of certain indicators related to time and cost perceptions of attributes aims to enhance the interpretation of results and provide a better quantification of the value of different transfer-related attributes.

First, the hypothesis that transfer time is perceived as higher than total travel time will be tested, as well as the perception of delay in comparison to total travel time. This analysis will allow to see if these two transfer-related time attributes are more impacting traveller travel time perception. To achieve that, the penalty factor of transfer time and delay are calculated. The respective equations used to calculate these indicators are provided in Equations 4.8, and 4.9.

$$\text{Ratio penalty of Transfer Time} = \frac{\beta_{transfertime}}{\beta_{tt}} \tag{4.8}$$

$$\text{Ratio penalty of Delay} = \frac{\beta_{delay}}{\beta_{tt}} \tag{4.9}$$

Then, the willingness to pay of travellers to avoid transfers compared to plane, car and direct train will be computed using the equation 4.10.

$$WTP\_mode = \frac{ASC_{mode}}{\beta_{tc}} \tag{4.10}$$

To conclude on the application of the model results, the penalty in terms of transfer time and value to cross-station transfer in comparison to cross-platform transfer will be computed. For the transfer time equivalent, equation x will be used and for the value penalty equation .

$$\text{Penalty of cross-station Transfer} = \frac{\beta_{Cross-station\_transfer}}{\beta_{\text{tc}}} \tag{4.11}$$

5 Interviews

The literature review previously showed that research on travellers' behaviour when they have to transfer during their trips has mostly been studied for short and medium distances, as well as for plane transfers for longer distances and international trips. Interviews are realised to complete the information extracted from this literature, focusing on long-distance international train travelling, to answer sub-question 1. Firstly, the data collection process is described in section 5.1, followed by a discussion of the data analysis process in section 5.2 and a presentation of the results in section 5.3. Lastly, conclusions of the interviews are given in section 5.4.

5.1. Data collection process

The data collection process started with the elaboration of the questions that will be asked to the participants. The interview questions were divided into three different sections:

- Participants' experience with long-distance international travel and modal preferences.
- Previous experience(s) with railway transfer(s).
- Important factors in railway transfers in long-distance international travel.

These questions allow to gain insights into which factors influence the traveller's choices when they travel on a railway route with transfer, as well as if there is heterogeneity of these influences according to previous experience and modal preferences. To ensure a manageable length and minimise respondents' time commitment, the interviews were limited to eight main questions. Some additional questions on contexts, like trip purposes and travelling company, were asked, if participants were willing to provide additional insights. These questions aimed to determine if varying contexts influenced their responses to the prior questions. The full interview questions preliminary set can be found in A.

The interviews were conducted at three different transportation hubs in the Netherlands: Rotterdam Centraal, Amsterdam Centraal and Amsterdam Schipol train stations, in September 2023. The data collection was focused specifically on stations from where international travelling is possible, targeting, for Rotterdam Centraal and Amsterdam Centraal, passengers using trains to travel internationally to destinations such as Paris, London or Brussels and at Amsterdam Schipol, the station of the airport, people using planes to travel internationally. This allows to get participants that could have different modal preferences, and then different opinions on railway transfers, or possible experience with this type of travel.

5.2. Data processing

The data obtained from the interviews was processed using the thematic analysis method, following the different steps described in the methodology chapter. The date familiarisation was made by reuniting all the answers into a single document. The coding part, as described in the methodology, was done using the software ATLAS.ti. The information given by the participants in relation to transfer was highlighted and coded. An example of how the coding process looks in the software is given in Figure 5.1, with the transcript text on the left and the codes identified from the transcript on the right. The coding of the data resulted in a list of 46 different codes.

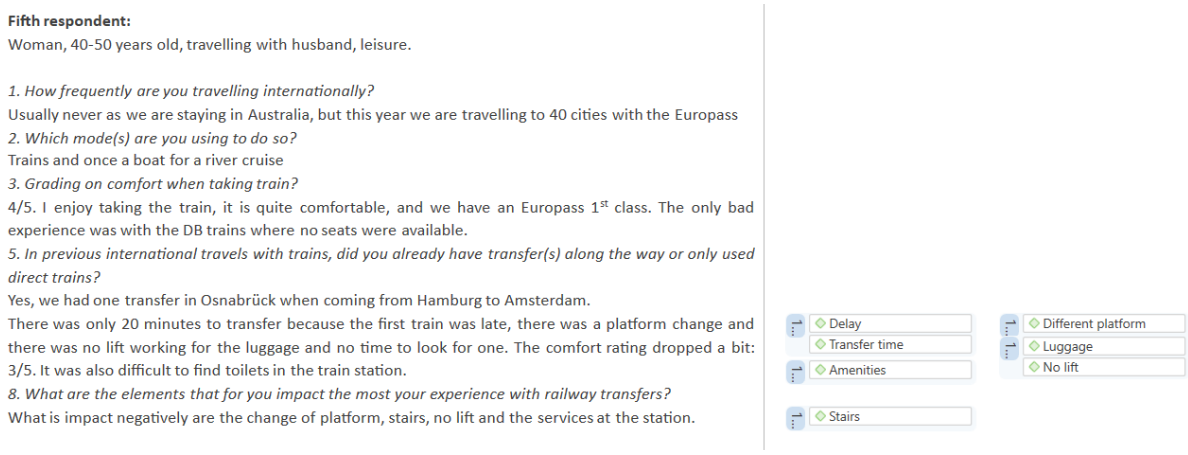


Figure 5.1: Example of coding process in ATLAS.ti

The different codes were then combined into different themes according to their similarities. During the process, two codes found in the second step were removed: “Train length” and “Exit time”, respectively related to the additional walking time in case of a long train and the time available to exit from a train. They were mentioned only marginally, by one person each, and do not seem relevant to the definition of the themes. The remaining 44 codes were used to create 21 different themes. Some of the codes were not combined with others but just became themes by themselves, such as “Transfer time”. The 21 themes found included 18 themes that can be defined as attributes and 3 themes that can be defined as contexts.

The themes were reviewed by comparing them to the transcript, to see if they were well representing what the respondents were seeing as important and impactful in railway transfers and if anything was missing.

After the review process, the number of themes stayed the same. Each theme was then defined, by giving a more concrete definition of what they represent, based on the answers of the respondents. The results were then analysed, and conclusions were drawn. These steps are developed in the next two sections of this chapter.

5.3. Results and analysis

The results of the interviews are given and analysed in this section, with a sub-section focusing on the characteristics of the respondents and their travel experience, and a second sub-section on the results of the thematic analysis.

5.3.1. Respondents characteristics and travel experience

The 11 respondents were evenly split by gender, with the majority aged between 20 and 30 years old. Most travelled for leisure and were occasional travellers, travelling for long distances internationally around 2 to 3 times a year. Trains were the preferred mode for long-distance travel, with planes also popular. Trains were also in majority found to be more comfortable by the respondents, in comparison to airplanes and the decrease in train comfort when a transfer was involved was mentioned by 2 travellers. Finally, a majority of the respondents, except two of them, had international experience with railway transfers.

5.3.2. Thematic analysis results

The output of the thematic analysis is presented in Table 5.1, with the themes in relation to transfers extracted from the text, their definition, based on the answers from the travellers, and the citation frequency. The citation frequency reflects how often the codes included in the different themes appear in the answers to the questions related to railway transfers.

Table 5.1: Themes extracted from the interviews

Theme	Definition	Citation frequency
Reliability	If first train will be on-time or have delay(impact on missing connection)	21
Transfer time	Time between the arrival of the first train and the departure of the following one	7
Stress/Anxiety	Stress and anxiety than making a transfer can bring	7
Information	Quality and accessibility of the available transfer information	6
Platform	Following train on same or different platform	6
Station facilities and services	Availability, quality and easiness to find facilities and services	5
Ticketing system	Unknown and different tickets systems between trip legs	5
Travel cost	Journey total cost	5
Lift/stairs	Presence of stairs or/and lift	4
Travel time	Journey total travel time	4
Comfort	Impact of transfer on the overall comfort experienced	3
Frequency	Frequency of the next train	3
Number of transfers	-	3
Station change	The next train is at another train station	3
Waiting time	Time to wait at station for connection	3
Safety	Safety perception at stations	2
Walking time	Time to walk from first to following train	2
Walking distance	Distance to walk between 2 trains	2

More detailed information on the most frequently cited themes is given in the remainder of the subsection.

Reliability
The predominant theme mentioned in the interviews was the reliability of the trains involved in the transfer, with more than 20 mentions overall, by more than half of the respondents. This theme included several codes such as “delay, “on-time” and “missed connection”. In respondents’ bad experiences in railway transfers, reliability was mostly associated with the delay of the first train resulting in a missed connection. This, in turn, led further to prolonged travel times, increased travel costs, and, for two respondents, an extra night spent in the city of the transfer.
However, delay of the first train was not seen as a burden in cases like in Switzerland where trains synchronise, minimising the likelihood of missed connection. Furthermore, delay was identified by one respondent as the most significant factor affecting railway transfers, and more specifically the delay of the second train that led during a trip to an increased waiting time late at a station, when no services

were available. When recounting their best experiences in railway transfers, three respondents mentioned they appreciated their journeys for the main reason that there were no delays.

Transfer time
Among the interview participants, transfer time emerged as the second most frequently discussed theme, along with stress and anxiety, with seven occurrences. Transfer time was mentioned as the most or second most important factor in transfer, after delay, by several of the respondents.
The travellers also had different opinions on the transfer time ideal value. One participant emphasised that a 10-minute transfer time was too short and could lead to stress and missed connections, whereas a 6-hour transfer time was too long but could allow to explore a city. The ideal transfer time, according to this respondent fell within the range of 20 to 40 minutes. A similar sentiment was echoed by another traveller who shared a positive experience involving a 40-minute transfer time and another one mentioned that 20 minutes was a short transfer time. In contrast to the opinion of these travellers, one respondent expressed a preference for shorter transfer times, while another participant communicated being unbothered by transfer time, citing familiarity with long transfer time associated with plane travel.

Stress and anxiety
Stress and anxiety arising from railway transfers were repeatedly mentioned by the interview participants, mostly in relation to transfer times perceived as insufficient and train station changes by public transport, such as the metro, during their transfer. One of the interviewees who had no prior experience with railway transfers, expressed concerns about potential anxiety and stress increase associated with railway transfers. Another respondent mentioned that a transfer time of between 20 and 40 minutes would be ideal for bringing “peace of mind”. The respondent previously mentioning 10 minutes transfer time as too short justified it as potentially creating stress unless frequent connecting trains were available.

Information
The significance of providing clear information regarding the transfer, both before and during the process, was mentioned by over a third of the survey participants. The experience of finding oneself in an unfamiliar station, dealing with an unknown transportation system and with an unfamiliar language were mentioned as elements impacting the transfer and influencing the need for clear information. Furthermore, one traveller emphasised that changes in the travel itinerary should be communicated at least a day before the travel begins. The need for good transfer information was deemed important for all types of travellers, from experienced travellers to passengers travelling for the first time abroad.

Platform
Two travellers highlighted transferring on the same platform as being related to their best railway transfer experience. Furthermore, another participant expressed a preference for same-platform transfers, especially when facing a short transfer time. Platform change was associated with a bad experience for one traveller, who mentioned it as the primary factor negatively impacting transfers, particularly in the context of short transfer times.

Station facilities and services
The quality and accessibility of facilities and services at stations, including toilets, water points and food were mentioned as impactful in railway transfer for four respondents. Among them, the respondent that has been subject to a long waiting time due to a delay of their second train complained about the lack of open facilities and services at the station during the late evening hours. Additionally, another respondent mentioned the importance of having access to a first-class facilities lounge, stating that it was making transfers “more pleasant” and should be made accessible to all travellers.

Ticketing system
The lack of integration among different ticketing systems for various railway legs, especially when operated by different operators, was highlighted as leading to uncertainty regarding transfers. In the event of a missed connection, passengers are unsure about their eligibility to board the subsequent train. For one respondent, an experience related to a missed connection secondarily due to the ticketing system was presented as their worst experience in railway transfers.

Travel cost
Travel cost was only considered in these interviews in comparison to railway transfer-related elements or to a railway transfer in itself. The balance between a long waiting time during a transfer and the inexpensive cost of the total journey was mentioned by one respondent. Another traveller considered travel cost as the most important element, whether or not the journey was direct or required a transfer.

Lift and stairs
The lack of lift at the platforms, necessitating the use of stairs when changing platforms, was mentioned by two respondents. This is seen as impractical, especially when carrying heavy luggage.

Travel time
Similarly to travel cost, travel time was considered in this interview, only in comparison to railway transfer. One respondent mentioned that travel time was the most important element when making decisions when travelling, and any transfer could lead to delays and travel time increases. As a result, direct routes were preferred over routes with transfers.

Other themes
Other themes were mentioned more sporadically by the respondents, who sometimes had divergent opinions on their importance. Some travellers mentioned a slight decrease in comfort when a transfer was involved in train travel. Two respondents highlighted that they did not mind shorter transfer times and the risk of missed connections if the frequency of the second train was higher. There were divergent opinions on the number of transfers, with one respondent unaffected by one or two transfers, while it mattered for another. Similarly, opinions on walking time and distance, in relation to changing stations and platforms and longer trains, varied. Some travellers viewed it negatively, while others did not consider it important. Waiting time also generated different opinions among the respondents, with one mentioning it could be an issue but not when compared to waiting before boarding a plane or dealing with traffic in a car. Finally, two travellers considered station changes to have a negative impact, and one traveller expressed safety concerns when waiting at a train station at night during transfer.

5.4. Conclusions and conceptual framework

Interviews were conducted at Amsterdam Centraal, Rotterdam Centraal and Amsterdam Schipol train stations about railway transfers in long-distance international travelling. Overall, the interviews provided valuable insights into the elements of train transfers being considered the most important for travellers in long-distance international travel. These insights, combined with the results of the literature review, are used in the construction of the conceptual framework of this study presented in Figure 5.2. The choice of the attributes, based on the interviews, is further explained in the following chapter.

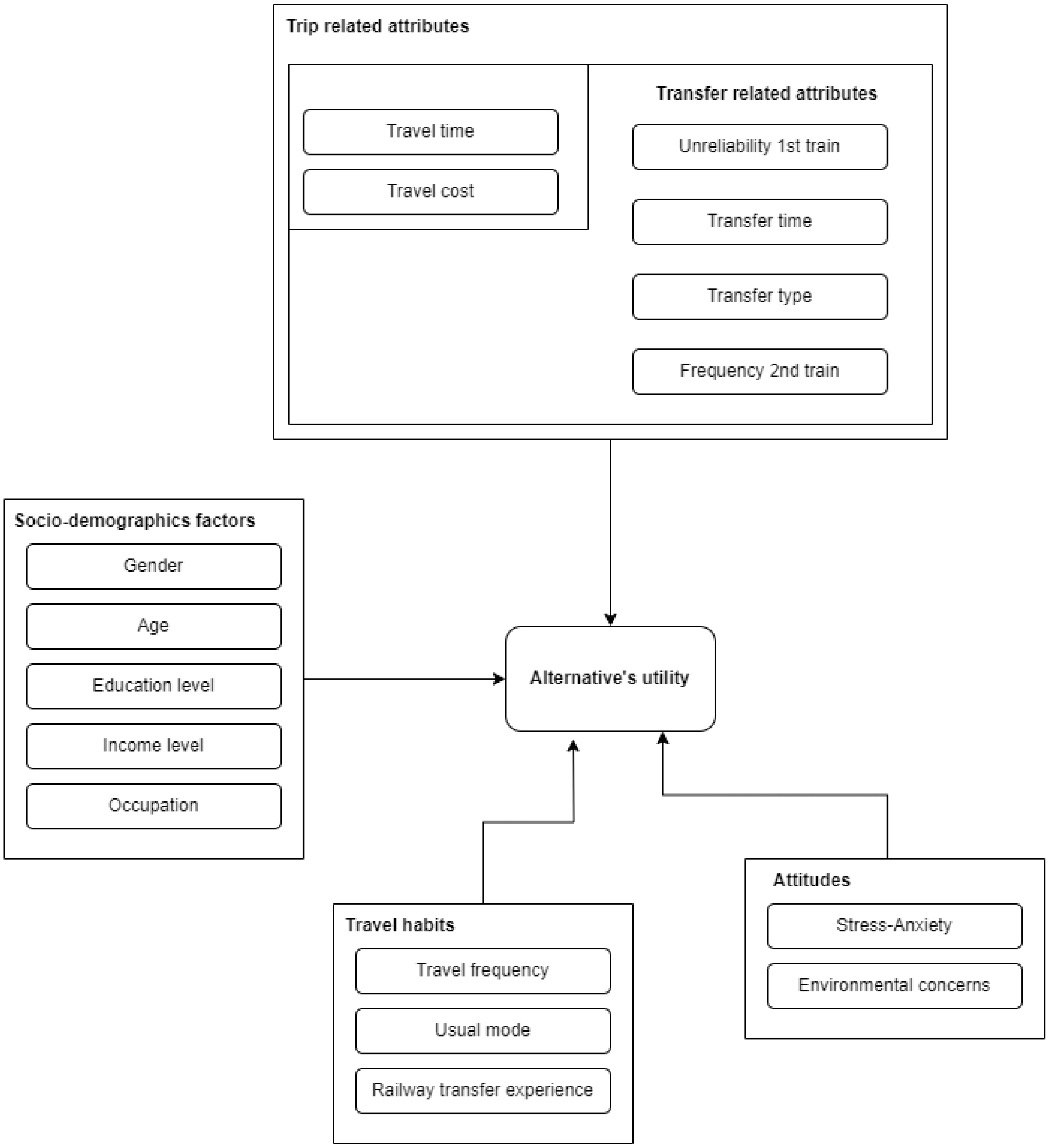


Figure 5.2: Conceptual framework of the study

6 Survey design

In this chapter, the data collection process, including the survey design, is given. The design of the choice experiment is firstly described in section 6.1, followed by a discussion on the construction of the questionnaire in section 6.2. Then the full iterative process of the survey construction and the pilot survey conducted are discussed in section 6.3, followed by the description of the final survey structure in section 6.4. Finally, the survey distribution process is described in 6.5.

6.1. Choice experiment design

6.1.1. Alternatives

To construct the choice set, the attributes and their levels are combined into alternatives, that are combined to form the choice set.

It was chosen to divide each choice into two parts. The first part includes a choice between two one-transfer alternatives, followed by a choice between the chosen alternative, a direct train, a direct plane and a car alternative, as shown in Figure 6.1. It was decided to construct the experiment this way to be able to estimate the trade-offs made between the railway transfer-related attributes, as well as the mode choice between a train with a transfer, a direct train, a plane and a car, in relation to the main objective of this research.

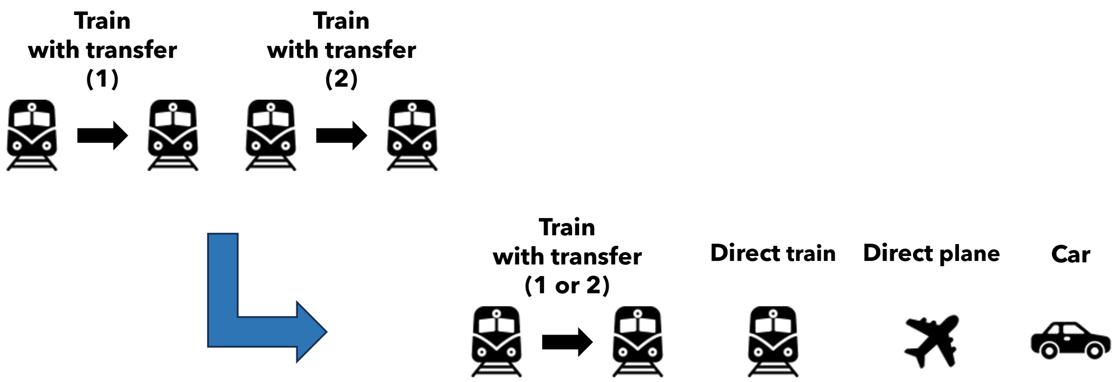


Figure 6.1: Alternatives that will be offered in the choice set

These specific modes are chosen as studies have shown that, in the EU, for the distance distances between 400 and 600 km, planes, trains and cars are the most used modes, as illustrated in the 2015 base scenario of the study by Donners, 2016 in Figure 6.2. When distances increase, train and car market share were found to reduce from 50% to 35% and 15% to 5% respectively when plane market share was found to rise from 26% to 55%. Given these market shares, excluding one of these modes in the study will decrease the validity of the research. Indeed, if not all the mode alternatives available to travellers in real life are included in the survey, this could result in an overestimation of the market share for the modes included, as the respondents could select an alternative they will not use in a real-life situation. The reason behind this specific range of distance selection will be further elaborated in the context sub-section.

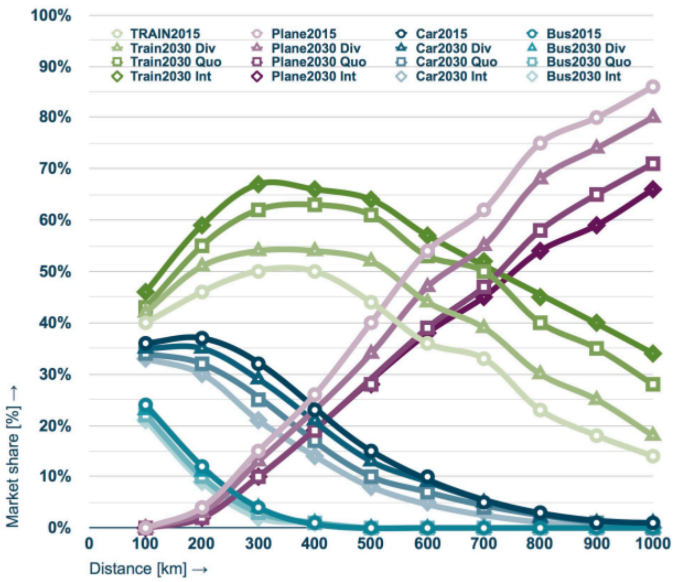


Figure 6.2: Modal split in the EU per distance, with different scenarios (Donners, 2016).

6.1.2. Choice experiment scope and context

Before defining the attributes and the attribute levels for the survey, it is important to establish the survey context, as the attributes and attribute level values will be influenced by it. The literature on travel behaviour and interviews conducted before the survey design both indicate that specific contexts can significantly influence travel choices. For this reason, the context of the study is fixed to avoid respondents making assumptions about the context and adapting their answers accordingly, without the researcher knowing about their context considerations. Furthermore, it was chosen not to make different experiments with different contexts, to prevent creating a too large choice set for the respondents, which will increase the task difficulty when answering.

In the literature on choice modelling, research has shown that the transfer penalty varies for travellers according to the distance travelled (Arentze & Molin, 2013) and that people exhibit different preferences and behaviours based on these distances. For this study, the scope will be made for a distance of approximately 500 kilometres by road between two European cities. As illustrated in Figure 6.2, at this distance, planes begin to overtake trains as the preferred mode of transportation, whereas trains dominate for distances shorter than 500 kilometres. A significant shift from plane use to rail use can then realistically be implemented for this distance.

The survey focuses on leisure trips taken with one travel companion (a friend or partner) and involves travelling with just one piece of hand luggage. It was chosen to focus on a leisure trip as it is assumed that the preferences could differ from a work trip, that is most of the time paid for by the employer. This typically makes business travellers less cost-sensitive and more time-sensitive, because of additional time constraints, such as scheduled meetings. Travelling with a companion can also influence behaviour, potentially making transfers less stressful and altering the perception of time during the trip. Additionally, the size of luggage can impact decisions related to making a transfer or influence transfer-related preferences.

The context of the choice experiment, as presented to the respondents, is shown in Figure 6.3.

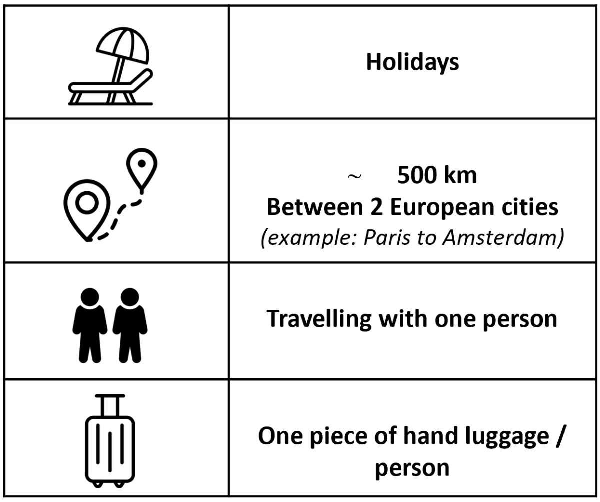


Figure 6.3: Context as presented in the survey

6.1.3. Attributes selection

The answer to sub-question 1 is used as input to determine which attributes will be used in the experiment. In this sub-section, the attributes selection is justified. The attributes selected for the train with transfer alternatives, how they are defined for this research and how they will be presented to the respondents in the survey are given in Table 6.1.

Table 6.1: Overview of the attributes used in the choice experiment

Attributes	Definition	Representation
Door-to-door travel time	Total travel time from city center to city center, including transfer time	hours and minutes, XhXmin
Travel cost	Total travel costs, including all costs	€
Transfer time	Time between the scheduled arrival time of first train and the departure time of the second train	minutes
Delay first train	Delays that could experience the first train	5 delays time having the same probability to happen in minutes
Frequency second train	Scheduled frequency of the second train at transfer station	One train every X hour(s)
Transfer type	-	4 different transfer types

An explanation of the reasoning behind the choice of these attributes is given below:

Travel time

In mode and route choice studies, and for all types of distances, travel time consistently emerges as one of the most critical attributes, with its impact extensively quantified across various studies (Behrens & Pels, 2012; González-Savignat, 2004; Mabit et al., 2013; Martín & Nombela, 2007). An increase in travel time has been observed to lead to a larger disutility, with, in long-distance travelling, train and car travellers being more time-sensitive compared to plane travellers (Martín & Nombela, 2007).

Furthermore, by examining the trade-offs travellers make between travel time and other attributes, it is possible to evaluate how people much people value certain transfer-related attributes in time (Espino, 2019).

Travel cost

Travel cost, often studied alongside travel time, is consistently recognised as one of the most important factors in mode and route choice studies. For some travellers, travel cost can be more important than travel time (Park & Ha, 2006) while for others, both attributes hold equal importance (González-Savignat, 2004; Martín & Nombela, 2007). By estimating the travel cost importance to travellers, it becomes possible to determine how much travellers are willing to pay for certain transfer characteristics variation or to avoid a transfer (Espino, 2019).

Transfer time

Different disutility values of transfer time, as well as non-linearity of this attribute were observed in the literature on regional railway (de Keizer et al., 2015) and long-distance plane travel (Johnson et al., 2014). Similarly to the literature, there was a heterogeneity of preferences and dis-preferences for transfer times among the respondents of the interviews. Furthermore, a non-linearity of the disutility of transfer time was also observed. It would be interesting to study from which turning point transfer time does bring disutility or utility for international travel by rail, since values are assumed to be different according to the modes used and the distances travelled.

Unreliability first train

Reliability/unreliability has been studied in transportation research under different forms, such as the impact of delays (Román et al., 2007) and the probability of being on time (Bergantino & Madio, 2020), but research has been limited on direct railway connections for railway services. In the interviews, the reliability of the first train was by far the most recurrent subject mentioned by respondents and was named as the main missed connection responsible. It is interesting to quantify the trade-offs people are willing to make between the unreliability of the first train, expressed as the delay that could occur, and the transfer time, in their transfer choice or choice to make a transfer. The unreliability could influence the importance passengers give to the transfer time as travellers could prefer a longer transfer time to not miss their connection in case of unreliability, or a shorter transfer time if the first train is more reliable.

Frequency second train

In previous studies on mode choice and route choice, the frequency was often mentioned with travel cost and travel time as important to consider, most of these studies focusing on direct trips. Frequency at connection point was studied only scarcely, with the conclusion that high-frequency connection was leading to a lower transfer disutility, in regional railway transport (Bovy & Hoogendoorn-Lanser, 2005; de Keizer et al., 2015). In the interviews, the frequency of the second train was mentioned as being associated with the reliability of the first train, as well as the transfer time, in connection to the risk of missing a connection. Respondents considered that it would be less important to miss a connection if the next train had a high frequency, which leads to less extra waiting time at the station and less impact on the total travel time than a low frequency. Trade-offs could be then observed between the frequency of the second train and the transfer time, or between the frequency of the second train and the reliability of the first train.

Transfer type

Different time penalties have been found for transfers in research according to the type of transfer, both for urban transport (Douglas & Jones, 2013) and regional transport (de Keizer et al., 2015), but has not been studied for long-distance railway transportation. In interviews, preferences were expressed about cross-platform transfers, as well as access to a lift when a change of platform is needed. Respondents expressed the possibility of accepting a smaller transfer time if these specific transfer conditions were met. Respondents notably evoked preferences to cross platform transfers, to avoid additional walking and stress related to having to cross the station to find the new platform. Respondents also mentioned difficulties with cross-station transfers involving stairs, especially when carrying luggage.

The attributes presented above result from the analysis of the attributes deemed to be important for travellers when a transfer is involved in the literature on choice modelling and in the interviews con-

ducted. Other attributes were found in literature and themes in the interviews and will not be used in this study, as explained in the rest of this paragraph.
The mention of stress and anxiety in relation to railway transfer came back often in the interviews but is difficult to quantify in a survey and passengers could over or under-estimate the level of stress they would experience during a railway transfer when answering a survey.
Furthermore, to limit the number of attributes, it was chosen not to include the number of transfers as an attribute and to include only one transfer within the train transfer alternatives. It is assumed that travellers will not choose a railway alternative with two or more transfers over a direct or one-transfer alternative by train. Additionally, as attributes like the unreliability of the first train and frequency of the second train are included in the model, having this information for each transfer will highly increase the computational difficulty of the model, as well as the complexity of the choices offered to the respondents, and lead to a decrease of the validity of the results.
Themes such as information regarding the transfer, station facilities and services at the station or the ticketing system are not accounted for in the study which is more focused on the operational side of a railway transfer. Furthermore, attributes such as walking time and waiting time will also not be considered, as they are assumed to be correlated to the transfer time, which will be considered in the study.
To finish, since the focus of the study is made on train transfers, for the direct alternatives: train, plane and car, only the travel cost and the travel time, which have been shown as the most determinant attribute of choice in literature, will be used as attributes.

6.1.4. Attribute levels selection

Even though stated choice experiments are based on hypothetical choices, it is important for the values to resemble what exists in reality, for the validity of the results. The attribute level values were determined by taking into account real data for the specific distance range of the study. In this sub-section, the selection process of the attribute levels per alternative is described.

Trains with transfer alternatives
The attribute levels of the train with transfer alternatives are summarised in Table 6.2.

Table 6.2: Overview of the attribute level values for the two train with one transfer alternatives

Attributes	Levels
Door-to-door travel time	3h30, 4h30, 5h30, 6h30
Travel cost	30, 60, 90, 120
Transfer time	10, 20, 30, 40
Delay first train	0,0,2,3,5 / 0,1,2,4,8 / 0,2,4,7,15 / 0,2,6,15,30
Frequency second train	One every 1h, one every 2h
Transfer type	Cross-platform / Cross-station with stairs/ Cross-station with escalator / Cross-station with lift

Door to door travel time
To determine the attribute level values, real data for trips between European cities within the 400-600 kilometres distance range by road was collected. Eight origin-destination pairs were considered, including routes such as Amsterdam to Paris and Amsterdam to London. This data was collected on the website Trainline.com, for a week distant by a month and a half from the research date, assuming that travellers typically research and book tickets within that timeframe. The minimum and maximum travel times for these eight OD pairs were rounded to the nearest half-hour and fixed as the first and fourth levels of the attribute. The second and third levels were then calculated, based on the first and fourth levels, in a way to maintain equal intervals between the attribute levels. No additional time was added for access to the train stations, as they are assumed to be located in the city centres, eliminating the need for extra travel time to access them.

Travel cost
The travel cost levels were constructed using a similar approach as the travel times. From all the costs found for travelling on one of the eight routes researched a month and a half later, the minimum and maximum costs were defined as the first and fourth levels, and the two other levels were calculated according to these values to maintain equidistance between the levels. As for the travel time, no additional cost was added, based on the assumption that train stations are located in city centres and no extra travel expenses are needed to access them.

Transfer time
The transfer time levels were established using the same method as travel time and travel cost, by extracting data from the Tranline.com website for eight selected OD-pairs, when non-direct options were available. The minimum and maximum values found were rounded to the nearest full decimal, to simplify the respondent's decision process, and were designated as the first and the fourth levels. The second and third levels were then derived to ensure equidistance between the attribute levels.

Delay first train
Unreliability has been discussed in the literature as presenting a challenge to represent, due to its dual dimensions, frequency and magnitude, and the lack of consensus on how to measure it Swierstra et al., 2017. It was found that the most efficient method to represent unreliability is to use five delay times, each with an equal probability of occurring. These values are derived from the 10th, 30th, 50th, 70th and 90th percentile of a log-normal distribution of delay times Alonso-González et al., 2020; Tseng et al., 2009. To calculate the five different delay times that have the same chance to happen per level, the degree of reliability that will be associated with each of the levels was first determined, based on regional and local rail services punctuality per country in the EU in 2018 (Statista, 2021). These statistics revealed that in 2018 in the EU, rail punctuality ranged from 62% to 99%, with an average of 90% and most countries exhibiting punctuality between 95% and 85% Different punctuality percentages were associated with the different levels as detailed in Table 6.3.

Table 6.3: Overview of the train reliability per level

Level	1	2	3	4
% Reliability	99	90	80	70

Since no specific data on delays in minutes for trains in Europe was available, the five different delays for each level were calculated based on the 10th, 30th, 50th, 70th and 90th percentile of four distinct log-normal distributions of delays. These distributions were based on the percentage of reliability defined earlier, assuming that a train is considered on time if it arrives within less than 5 minutes of its scheduled arrival.

Frequency second train
For the eight OD-pairs selected, research was once again conducted on Trainline.com to determine the values for the frequency of the second train at the transfer station during a normal weekday. The frequencies were found to range from one train every 30 minutes to one train every four hours, with the most frequent value found being every hour or every two hours. The option with one train every 30 minutes was excluded due to its specific relevance to the Brussels-Paris route with frequent connections for daily commuters. The option of one train every four hours was also omitted, as it is assumed that travellers will not select this alternative if it was included in a choice set.

Transfer type
The levels were determined based on people's concerns from the interviews, who mostly mentioned cross-platform transfers, in opposition to cross-station transfers, and the use of lifts and stairs to change platforms.

Direct alternatives
Their values, given in Table 6.4 were chosen to be fixed, as the study is focusing on railway transfers.

Table 6.4: Overview of the attribute values for direct train, plane and car alternatives

Mode	Travel time (hours)	Travel cost (€)
Direct train	4.5	110
Plane	3.75	125
Car	6.75	90

Direct plane
To determine the travel time and costs, the same method as that used for the train with transfer alternatives was applied, but using the website Skyscanner.com to find the real-life data. Averages were calculated between the minimum and maximum cost and time found within the eight OD-pairs. For the travel cost, an average shuttle price from the city centre to the airport was added to the average price using real data from the OD-pairs cities used. To obtain the travel time, 1h30 for the assumed time people arrive before their flight for security check and find their gate was added, as well as an average access time from the city centre to the airport. It is assumed that people do not proceed to luggage check-in, as they travel with a small cabin suitcase.

Direct train
The attribute level values were calculated using the same process as with the direct plane but using the website Trainline.com to find data, focusing on direct train connections. No additional time or cost was added to the price found, similar to the train with transfer alternatives, as the train stations are assumed to be in the city's centres.

Car
For this alternative, travel time and travel cost were researched for the eight OD pairs on the website ViaMichelin.com and average values were calculated for both attributes. An additional 30 minutes was added to the travel time to account for potential traffic delays and rest stops along the route.

6.1.5. Experimental design

The previously chosen attributes and attribute levels were used as input in the Ngene software to design the experiment. As outlined in the methodology, a fractional factorial orthogonal design was used to construct the choice set. Furthermore, to simplify the design and reduce the number of required choice sets, it was decided to construct the choice set sequentially. With this approach, the orthogonality of attributes holds within each alternative but not between alternatives, as opposed to simultaneous designs (ChoiceMetrics, 2018). This type of construction is feasible because the trains with transfer alternatives are unlabelled alternatives, while the direct train, plane and car are fixed alternatives, that do not need to be considered in Ngene's utility specification. While correlations between different alternatives are generally not an issue, minimising these correlations is still preferable to reduce the standard errors of the parameters. This can be achieved by iteratively generating designs in Ngene.
A first design, consisting of 12 rows (or choices) was found in Ngene. The design was then optimised to eliminate the potential interaction effect between the transfer time and the delay of the first train attributes, as well as to address the potential non-linearity of the transfer time attribute parameter. To achieve this, the interaction between transfer time and delay was specified and the number of rows was increased to the next possibility, 16 rows. Given that 16 choices were considered as a too high number of choices for one respondent, blocking was applied to the design. Blocking allows the choice set to be divided into smaller blocks, each presented an equal number of times to the participants. Two blocks were applied to the design, resulting in two blocks of 8 choices per respondent. The final experimental design script implemented in Ngene is provided in Appendix B.

6.2. Questionnaire design

After the design of the experiment, the questionnaire was designed in Qualtrics, to present the choices to the survey participants.

6.2.1. Choice situations

As mentioned in the previous section, the choices offered to the respondents were divided into two smaller blocks of 8 choices, randomised for the respondents. This means that the two choice sets have the same chance of being answered by the participants. Before the choices are presented in the survey, the context, as well as all the attributes, are described so that not excessive information is communicated, to avoid the respondents skipping it, but enough information is available for the travellers, to not make assumptions about the attributes. As mentioned in the alternatives description, in each of the 8 choices, the respondents are first asked to make a choice between two trains with one transfer alternative. Then, they are asked to make a choice between the option they previously chose, and the three base alternatives, the direct train, the plane and the car. A choice example is given in Figure 6.4 for the first part of a choice and in Figure 6.5 for the second part of a choice.

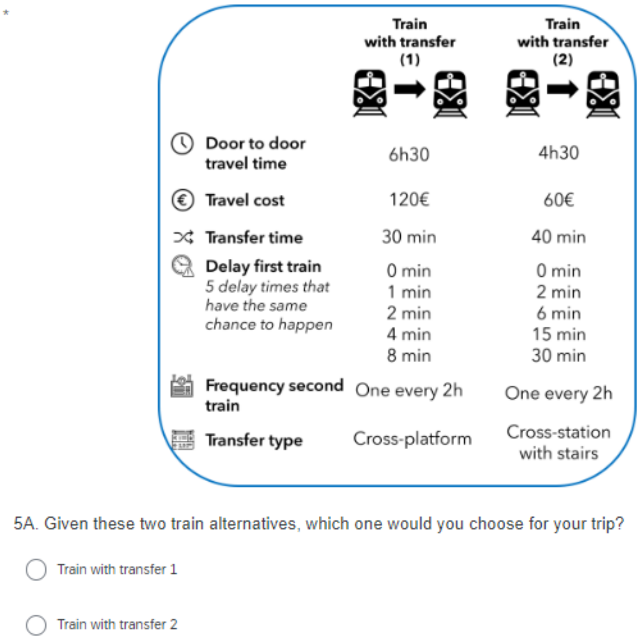


Figure 6.4: Illustration of the first part of a possible choice

6.2.2. Socio-demographic questions

Additionally to external factors, the respondents' characteristics can also play a role in their decisions. A few socio-demographic questions were added to the survey to measure how certain characteristics influence travellers' preferences. The characteristics asked are the following ones: gender, year of birth, occupation, education level, household annual gross salary, driving license and access to a car.

6.2.3. Travel habits

Furthermore, participants are asked questions about their travel habits. Before presenting the choice scenarios, travellers are asked how often they travel per year and which modes of transportation they typically use. This helps to determine whether their choices are influenced by their previous experiences. At the end of the survey, respondents are asked about their experience with railway transfers. This question is placed at the end to avoid influencing their previous choices involving train transfer options.

6.3. Design process and pilot survey

The survey design process began with the creation of a survey script including all the necessary information and questions that will be presented to the participants. This draft, along with a preliminary version of the Ngene syntax, was shared with the thesis supervisors, to solicit their input. Based on

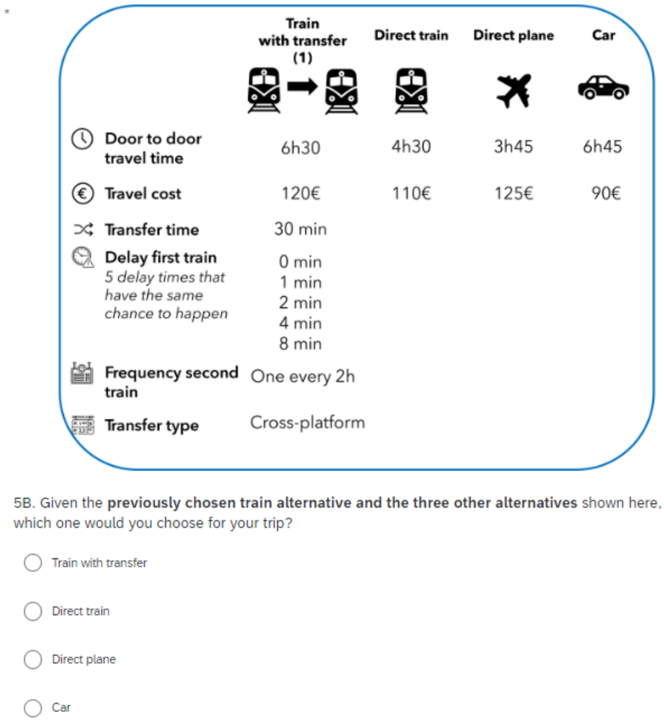


Figure 6.5: Illustration of the second part of a possible choice

their feedback, a first version of the survey was developed in Qualtrics and then forwarded to them for further recommendations. Following their suggestions, a second version of the survey was created. Key adjustments from the first version included adjustments to the travel cost, the frequency of the second train and the unreliability levels of the first train. Additionally, the choice designs were modified to enhance visibility for respondents on both computer and phone platforms. Following these modifications, a pilot study was conducted, involving 10 respondents from different socio-economic backgrounds, both within and outside the transportation field. The main objectives of the pilot survey were to assess the clarity of the survey, particularly focusing on the choice experiment, and to ensure that the survey could be completed within approximately 10 minutes. Based on feedback from the pilot survey and additional input provided by the supervisors, a third version of the survey was developed and sent to all committee members. This last round of feedback led to further adjustments in the experimental design in Ngene, specifically to account for interactions between the first train delay and the transfer time, resulting in a fully updated choice set.

6.4. Survey structure

The survey is structured as follows:

1. *Introduction and consent to participate*
2. *Introductive questions*
3. *Stated choice experiment*
4. *Socio-demographics and travelling habits questions*

The detailed survey as distributed is given in Appendix C.

6.5. Survey distribution

The survey was distributed over one month, from April to May 2024, mostly in the Netherlands. The survey was initially distributed through anonymous links shared within the researcher's personal and professional network, with further dissemination achieved via snowball, where participants were encouraged to share the survey with their contacts. To reach a border audience with different socio-demographic backgrounds, flyers including a QR code linking to the survey were designed and distributed at train stations with international departures, such as Rotterdam Centraal and Amsterdam Centraal. Flyers were also placed at the Technical University of Delft. The survey and the related study were presented to the potential respondents as being focused on long-distance travel in Europe. However, the specific emphasis on railway transfers was not disclosed to avoid influencing their choices.

7

Survey results

7.1. Descriptive statistics

Following the data collection, the gathered information is analysed. This section presents the descriptive statistics of the obtained data, helping to understand the characteristics of the survey respondents. Firstly, the steps taken to prepare the data are described in sub-section 7.1.1. Following the data preparation, sub-section 7.1.2 provides an overview of the characteristics of the sample, including the socio-demographic characteristics that are compared to the Dutch population, and the travel habits of the respondents. To finish, a description of the mode choices is given in sub-section 7.4 and a conclusion on the descriptive statistics is given in sub-section 7.1.4.

7.1.1. Data preparation

Before the analysis, the data collected through the survey is prepared. Of the 302 responses collected, 76 uncompleted answers, approximately 25% of the total, were removed, resulting in 226 complete responses. Additionally, responses that did not meet the following criteria were excluded from the data set, as they could negatively impact data validity :

- Responses with a completion time below five minutes, with an acceptance margin of 10 seconds.
- Responses with identical answers for all questions, such as selecting 'Train with transfer 1' for all eight choices in the first part of the choices.

Responses with a completion time below five minutes were removed from the analysis, as this is considered the minimum time necessary for a respondent to complete the survey and thoroughly read and understand the descriptions of the alternatives and their attributes in the choice set. A total of 22 responses were completed in less than five minutes. After removing these resp, the remaining number of valid responses was 204. Responses where the same answer was consistently chosen were considered indicative of random choices. This criterion was applied to the first step of the choices, as respondents could have strong modal preferences and consistently chose the same option in the second part. Two additional responses were removed, resulting in a data set of 202 responses.

No adjustments were needed between the answers from Block 1 and Block 2, as they were almost equally represented, with respectively 100 answers and 102 answers. Thus, the orthogonality of the experiment is maintained.

Since each respondent answered to 8 choices, the final data set for the choice experiment includes 1616 observations.

7.1.2. Sample characteristics

The survey gathered information on respondents' socio-demographics and their long-distance travel habits within Europe. This sub-section provides a detailed overview of these aspects.

Socio-demographics characteristics
The socio-demographic characteristics describe the composition of the sample. This is useful for interpreting the choices' results and assessing their possible generalisation to a broader population.

Table 7.1 presents the count and percentage for the various socio-demographics categories surveyed, compared to the Dutch population aged 18 to 90 years. The sample is compared to this population as the survey was primarily distributed to Dutch residents over 18. The population data is drawn from CBS's 2021 dataset (CBS,2022), since it is the most recent year with complete data available for these categories. However. no data on work activity was available for comparison. To ensure alignment with the Dutch population data and facilitate comparison, some socio-demographic responses were aggregated into broader categories. For instance, low-level education includes primary education, intermediate level includes high school education, and high level refers to respondents who completed a university degree, such as Bachelor's, Master's or PhD. Additionally, the number of household annual gross income categories was reduced from eight to five. In later stages of the research, further aggregation of categories will be performed to ensure a significant number of responses (N>30) per category, which is necessary for obtaining statistically significant results on the impact of socio-demographics and travel habits on the results.

Table 7.1: Socio-demographic characteristics of the sample compared to Dutch population

Socio-demographic	Category	Sample		Dutch population
		Count	%	
Gender	Male	90	44.6%	49.5%
	Female	109	54%	50.5%
	Prefer no to say	3	1.5%	
Age	Under 20	0	0%	3.1%
	21-30	154	76.2%	16%
	31-40	25	12.4%	15.5%
	41-50	4	2%	15.3%
	51-60	9	4.5%	17.9%
	61-90	6	3%	30.6%
	Not mentioned	4	2%	
Education level	Low level	0	0%	8.6%
	Intermediate level	13	6.4%	59.3%
	High level	188	93.1%	32%
	Unknown	1	0.5%	
Work status	Employed full-time	86	42.6%	
	Employed part-time	16	7.9%	
	Unemployed	5	2.5%	
	Retired	4	2%	
	Student	85	42.1%	
	Other	6	3%	
Income	Less than 10.000€	45	22.4%	2.5%
	10.000€ to 30.000€	38	18.9%	17.2%
	30.000€ to 50.000€	52	25.9%	20.6%
	50.000€ to 100.000€	45	22.4%	31%
	More than 100.000€	21	10.4%	28.7%
Driving license	Yes	170	84.2%	49%
	No	32	15.8%	

Within the sample of 202 individuals, women are slightly more represented than men, which is similar to the overall Dutch population. Younger individuals are significantly over-represented in the sample, with 76.2% of the participants aged between 21 and 30 years old, calculated from the collected dates of birth. This largely contrasts with the older demographic profile of the Dutch population.

The survey respondents predominantly fall into the high level of education category, with 93.1% holding a university degree, which highly differs from the Dutch population, where a larger proportion has completed an intermediate level of education.
Regarding work status, the sample is mainly composed of students and full-time employees, respectively representing 42.1% and 42.6% of the sample. Household annual gross income distribution varies more widely within the sample, with a higher representation of respondents reporting incomes below €10,000 or between €50,000 and €100,000. This pattern likely reflects the significant presence of students and full-time workers in the sample. In contrast, the Dutch population shows a higher concentration of households earning between €100,000 and €200,000 annually.
To finish, a vast majority of respondents declared having a driving license, and regardless of license status, three-quarters of the participants can access a car. Car ownership among the sample is significantly higher than in the Dutch population, where approximately half of the adult population holds a driving license.

Additionally, a chi-square test was computed to further assess if the sample significantly differs from the population. The chi-square test results, presented in Table 7.2 indicate that only gender is not statistically different from the Dutch population at a 5% confidence level. This suggests that the age, education level, income and driving license distributions of the sample are not representative of the population. It needs to be considered when analysing the results of the discrete choice models.

Table 7.2: Chi-square test results of the sample compared to Dutch population

	Chi-square	Df	p-value
Gender	1.45	1	0.23
Age	569.20	5	0.00
Education level	349.72	2	0.00
Income	341.57	4	0.00
Driving license	99.71	1	0.00

Travel habits
Following the description of the respondent's socio-demographic characteristics, an overview of the participants' travel habits in Europe is provided. This information is important to know more about the sample's previous travel experiences and give a potential indication of their initial modal preferences, which could influence the choices made in the survey.

In the survey, respondents were first asked about the frequency of their long-distance travel abroad within Europe. The results presented in Figure 7.1 reveal that most of the sample consists of occasional travellers, who undertake long-distance trips abroad 2 to 3 times a year. Non-experimented travellers, who rarely or never travel for long distances abroad are the less represented category in the sample. Overall, the majority of the sample, 78.2%, engages in this kind of trip more than once a year.

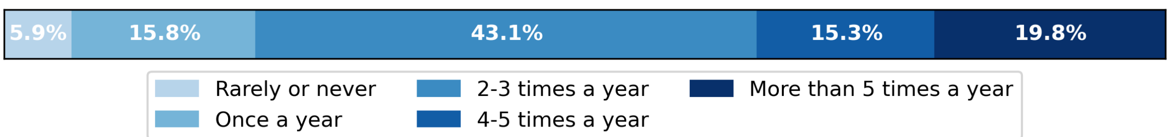


Figure 7.1: International travel frequency of the sample in Europe

The primary modes of transportation used by the respondents for these trips are illustrated in Figure 7.2. The plane is the most frequently chosen mode, selected by over half of the respondents, followed by the train, which is used by more than a quarter of the sample, and then by car. Other modes, such as the bus, are used infrequently. These findings contrast with the modal split reported by Donners, 2016, where for a 500-kilometre distance, plane, train and car usage were found to be 40%, 45% and 10% respectively. The mode shares in the sample are more comparable to those typically seen for distances of 600 kilometres for planes, 800 kilometres for trains, and 400 kilometres for cars Donners, 2016. This suggests that the sample exhibits a higher reliance on planes and cars, with a lower usage of trains for long-distance travel in Europe, compared to the broader EU population.

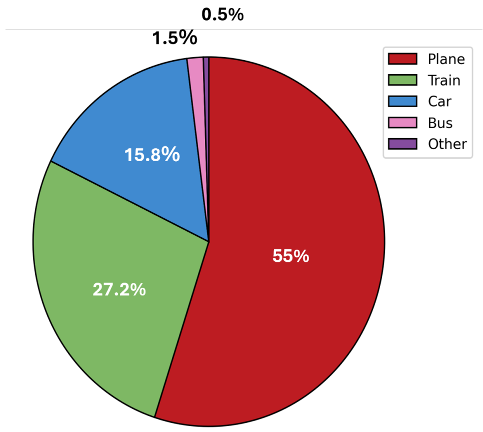


Figure 7.2: Respondents main mode use for long-distance international travel in Europe

After the choice experiment completion, travellers were asked about their previous experiences with railway transfers during long-distance travel, including any negative experiences they encountered during these transfers. These questions were presented after the choice tasks to avoid influencing the participants' choices, as the study's focus on railway transfers was not explicitly disclosed. Figure 7.3 shows that the majority of the respondents had previously made a transfer during an international rail journey. Among the negative experiences reported, missed connections were the most common issue, accounting for more than a quarter of the negative experiences. This was followed by a high proportion of reports about excessively long waiting times and difficulties in finding the correct platform. The "other" category included a variety of issues, such as cross-station transfers, lack of station personnel, delays on the first train reducing transfer time, unfamiliar stations, cancellations, and insufficient seating on the second train.

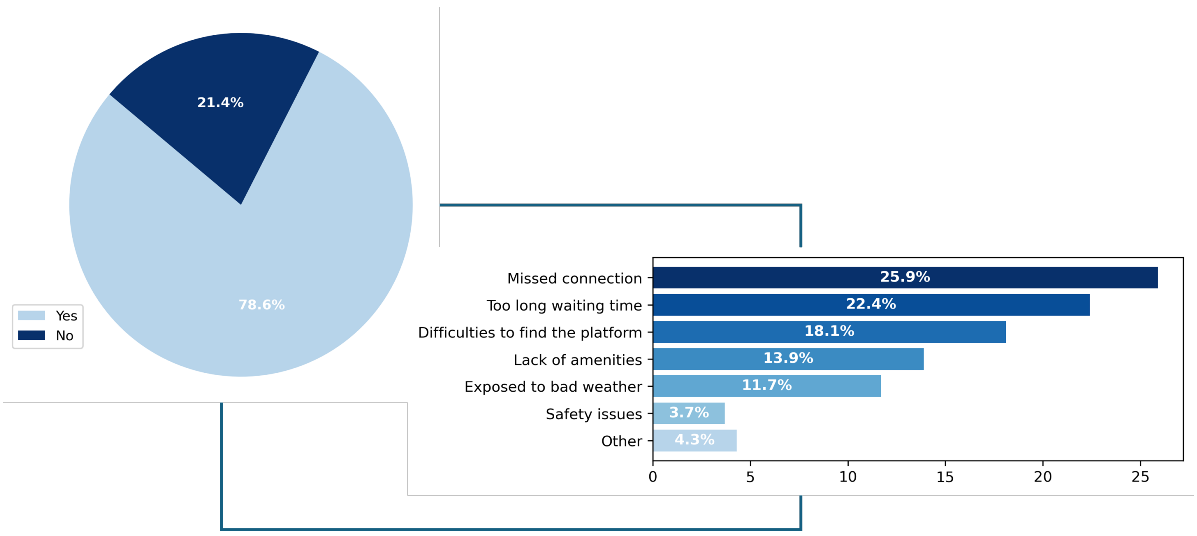


Figure 7.3: Share of previous railway experience and associated negative experiences

7.1.3. Mode choice overview

The mode choice overview represented in Figure 7.4 were determined by considering the final answer made by the participants for each of the eight choices offered to them. The ”train with transfer” and ”direct train” alternatives are treated as distinct modes, as they will be considered as different mode alternatives in the discrete choice models that will be estimated in the next section. The ”train with transfer” emerged as the most frequently selected option, chosen in 64% of the cases, followed by the ”direct train” alternative at 20.1%. The plane and car options were chosen less frequently, at 11.8% and 4.1% respectively. The results from the discrete choice models will provide insights into the factors influencing these choices, including the attributes of each alternative and the characteristics of the participants.

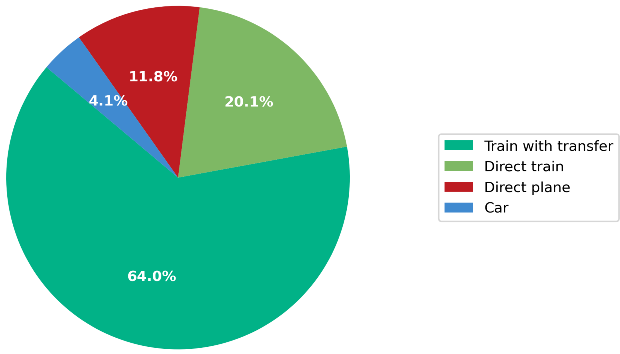


Figure 7.4: Mode choice results

7.1.4. Descriptive statistics conclusion

This section provided a detailed overview of the socio-demographics, travel habits, and mode choices in the choice experiment of the sample.
The sample is mostly composed of young individuals aged 21 to 30 years, who hold a high degree of education, are either students or employed full-time and possess a driving license. Chi-square tests revealed that the sample statistically differs from the Dutch population in terms of age, education level and income level. Only the gender distribution was found to be not significantly different from the population. These demographic differences should be kept in mind when interpreting the discrete choice model results.
The majority of the sample is accustomed to travelling abroad on long distances, with nearly 80% undertaking such trips at least twice a year. Planes are the most commonly used mode of transportation for these journeys, followed by trains and cars. Additionally, over two-thirds of respondents have experience with railway transfers, with the most common negative experiences involving missed connections or excessively long waiting times. In the choice experiment, the ”train with transfer” alternative was preferred by the majority, accounting for 64% of the total choices, followed by the ”direct train” option.

7.2. Discrete choice modelling

In this section, the results of the estimation of two discrete choice models: a Multinomial Logit model (MNL) and a panel Mixed Logit (ML), are presented. This section focuses on analysing the participants’ modal preferences, specifically addressing sub-research questions 2 and 3, which investigate the key factors influencing railway transfers and how personal characteristics impact participants’ mode choices. The MNL model is introduced first in sub-section 7.2.1, serving as a baseline for comparison. Then, subsection 7.2.2 will cover the estimation of a panel ML model, accounting for individual-specific preferences.

7.2.1. Multinomial logit model

Initially, a basic MNL model including all the attributes from the survey is estimated. Then, different models are estimated and compared to this base model to identify a more performing model. First, a model incorporating alternative specific parameters is computed. Following this, models testing for the potential interactions between different railway transfer attributes and for potential non-linearity of the transfer time effect on utility are explored. The most performing model out of the estimated models is then established as the new base model. Following this, interactions between socio-demographic characteristics and travel habits with various attributes are examined. The most significant interactions are then integrated into the base model to formulate the final MNL model.

Base MNL model

To compute the MNL model, the five different alternatives: Train with transfer 1, train with transfer 2, direct train, plane and car are considered together. Their respective utility functions, used to estimate the base model, are presented in Equations 7.1, 7.2, 7.3, 7.4 and 7.5. The terms used in these utility functions are described in Table 7.3.

$$\begin{aligned} V_{transfer1} = {} & \beta_{tt} \cdot tt_{transfer1} + \beta_{tc} \cdot tc_{transfer1} + \beta_{transfertime\_transfer} \cdot transfertime\_transfer1 \\ & + \beta_{delay\_transfer} \cdot delay\_transfer1 + \beta_{Lift\_transfer} \cdot Lift\_transfer1 \\ & + \beta_{Escalator\_transfer} \cdot Escalator\_transfer1 + \beta_{Stairs\_transfer} \cdot Stairs\_transfer1 \\ & + \beta_{frequency\_transfer} \cdot Dummy\_frequency\_transfer1 \end{aligned} \tag{7.1}$$

$$\begin{aligned} V_{transfer2} = {} & \beta_{tt} \cdot tt_{transfer2} + \beta_{tc} \cdot tc_{transfer2} + \beta_{transfertime\_transfer} \cdot transfertime\_transfer2 \\ & + \beta_{delay\_transfer} \cdot delay\_transfer2 + \beta_{Lift\_transfer} \cdot Lift\_transfer2 \\ & + \beta_{Escalator\_transfer} \cdot Escalator\_transfer2 + \beta_{Stairs\_transfer} \cdot Stairs\_transfer2 \\ & + \beta_{frequency\_transfer} \cdot Dummy\_frequency\_transfer2 \end{aligned} \tag{7.2}$$

$$V_{directtrain} = ASC_{directtrain} + \beta_{tt} \cdot tt_{train} + \beta_{tc} \cdot tc_{train} \tag{7.3}$$

$$V_{plane} = ASC_{plane} + \beta_{tt} \cdot tt_{plane} + \beta_{tc} \cdot tc_{plane} \tag{7.4}$$

$$V_{car} = ASC_{car} + \beta_{tt} \cdot tt_{car} + \beta_{tc} \cdot tc_{car} \tag{7.5}$$

For the analysis, travel time was converted from hours to minutes, and instead of using dummy variables to represent the unreliability of the first train, continuous values in minutes were used. For each level, the average of the five possible delay values was computed and used as variable values. This approach allows for easier comparison between travel time, unreliability of the first train and travel time, facilitating a more accurate assessment of the trade-offs individuals make in their mode choices. Furthermore, treating unreliability as a continuous variable simplifies the model by using a single parameter rather than three parameters for three dummy variables.
The attributes ”transfer type” and ”frequency of the second train” were dummy-coded due to their categorical nature. Their coding details are provided in Table 7.4, with ”Cross-platform” serving as the reference category for transfer type and ”every 1h” as the reference category for the frequency of the second train.

The full code used for the computation of the base model, with all the parameters tested, can be found in Appendix D.

Alternative specific parameters

The MNL model was re-estimated by turning generic parameters into alternative-specific parameters to

Table 7.3: Description of the terms used in the utility functions

Element	Description
$V_{transfer1}$	Utility of the Transfer 1 alt
$V_{transfer2}$	Utility of the Transfer 2 alt
$V_{directtrain}$	Utility of the Direct train alt
V_{plane}	Utility of the Plane alt
V_{car}	Utility of the Car alt
$ASC_{directtrain}$	Alternative specific constant of the Direct train
ASC_{plane}	Alternative specific constant of the Plane
ASC_{car}	Alternative specific constant of the Car
β_{tt}	Parameter for travel time
β_{tc}	Parameter for travel cost
$\beta_{transfertime\_transfer}$	Parameter for transfer time
$\beta_{delay\_transfer}$	Parameter for unreliability first train
$\beta_{Lift\_transfer}$	Parameter for cross-station with lift transfer type
$\beta_{Escalator\_transfer}$	Parameter for cross-station with escalator transfer type
$\beta_{Stairs\_transfer}$	Parameter for cross-station with stairs transfer type
$\beta_{frequency\_transfer}$	Parameter for frequency of the second train
$tt_{transfer}$	Variable for travel time for the transfers alts
$tc_{transfer}$	Variable for travel cost for the transfers alts
$transfertime\_transfer1$	Variable for transfer time
$delay\_transfer1$	Variable for the average delay of the first train
$Lift\_transfer1$	Dummy variable for the lift
$Escalator\_transfer1$	Dummy variable for the escalator
$Stairs\_transfer1$	Dummy variable for the stairs
$Dummy\_frequency\_transfer1$	Dummy variable for the frequency of the second train
tt_{train}	Variable for the direct train travel time
tc_{train}	Variable for the direct train travel cost
tt_{plane}	Variable for the plane travel time
tc_{plane}	Variable for the plane travel cost
tt_{car}	Variable for the car travel time
tc_{car}	Variable for the car travel cost

the alternatives, to evaluate their impact on model performance. Given that the two ”train with transfer” alternatives are unlabelled, only travel time and travel cost were tested as alternative specific parameters for the direct train, plane and car alternatives, and applied generically to both ”train with transfer” alternatives.
First, a model including travel time as an alternative specific parameter was estimated. Despite the high statistical significance of these parameters, with p-values ranging from 0 to 4.9×10^{-9}, the model demonstrated increased complexity and reduced performance compared to the generic mode. This is shown by a similar Likelihood ratio test value, higher AIC and BIC values, and a decrease in the adjusted rho square value. A similar assessment was conducted with travel cost as an alternative specific parameter, leading to similar results, with the high significance of the parameters but a significant decline in the model's performance compared to the base model.
These results illustrate the non-uniformity of the influence of travel time and travel cost along the different transportation modes. However, since the addition of the alternative specific parameters led to a decrease in the model fit to the data, it was decided to keep all parameters tested as generic in the base model to maintain model performance. The performance comparison of these two models with the base model is presented in Table 7.5 and the parameter estimates are provided in Appendix D.

Interactions in-between transfer related attributes
It is hypothesised that interactions may exist between the different attributes related to railway transfers. For instance, a significant delay of the first train or the transfer type might potentially affect the perceived utility of the transfer time variable for the travellers.

Table 7.4: Dummy coding for the transfer type and the frequency of the second train

Transfer type	Lift_transfer	Escalator_transfer	Stairs_transfer
Cross platform	0	0	0
Cross station with lift	1	0	0
Cross station with escalator	0	1	0
Cross station with stairs	0	0	1
Frequency second train	Dummy_Frequency_transfer		
Every 1h	0		
Every 2h	1		

Table 7.5: Comparison of the models' performance with and without alternative specific parameters

Model	Likelihood ratio test	AIC	BIC	Adjusted ρ^2
Generic model	2088.297	3135.406	3194.671	0.3972
Travel time alt. specific	2088.297	3141.406	3216.834	0.3961
Travel cost alt. specific	2088.297	3141.406	3216.834	0.3961

The following interactions were tested:

- Delay and transfer time (with continuous values and dummy)
- Transfer time and frequency
- Delay and frequency
- Transfer time and cross-station transfer with lift
- Transfer time and cross-station transfer with escalator
- Transfer time and cross-station transfer with stairs

For the interaction between delay and transfer time, the interaction was tested using the original variable values but also with a dummy variable taking the value 1 when the delay was equal or superior to the transfer time and the value 0 otherwise.
The performance of these models compared to the base model are shown in Table 7.6 and their parameter estimates can be found in Appendix D.

Table 7.6: Comparison of the performance of the models with interactions between transfer-related attributes

Model	Likelihood ratio test	AIC	BIC	Adjusted ρ^2
Generic model	2088.297	3135.406	3194.671	0.3972
Delay and transfer time	2088.315	3137.388	3202.041	0.3969
Delay and transfer time, dummy	2088.409	3137.294	3201.947	0.3969
Transfer time and frequency	2092.825	3132.879	3197.531	0.3977
Delay and frequency	2090.372	3135.331	3199.984	0.3972
Transfer time and lift	2088.915	3136.788	3201.441	0.3970
Transfer time and escalator	2088.337	3137.366	3202.019	0.3969
Transfer time and stairs	2088.721	3136.983	3201.635	0.3969

The estimated interaction parameters do not have highly significant values, the parameter for the interaction between transfer time and frequency being the most significant out of the interaction parameters tested, with a p-value of 0,068. This illustrates that there is no statistical significant interaction between delay and transfer time, delay and frequency and transfer time and transfer type, but a statistically significant interaction could exist between frequency and transfer time. An increase in transfer time has a slightly more negative impact on utility when it is combined with a decrease in the frequency of the second train. This effect is reflected in the interaction parameter value of -0.045. The model performance results indicate that only the interaction between transfer time and frequency and the interaction between delay and frequency slightly improve the model fit according to the likelihood ratio test. However, when considering the AIC and BIC which account for model fit regarding the number of parameters, none of these models outperform the base model. Consequently, adding any of these interaction parameters would only increase the model complexity without improving its performance. Therefore, it was chosen to not include any of these interactions in the base model.

Non-linearity transfer time
To conclude on the estimation of the base model, non-linearity was investigated for the transfer time parameter. Indeed, existing literature on transportation transfers, along with insights from the conducted interviews suggested that the utility associated with transfer time may exhibit non-linear behaviour.
The non-linearity in transfer time was first tested with a quadratic parameter alone, which can allow to see if the utility is following a u-shape function, and then with both a quadratic and a cubic parameter, to see if the utility is following an S-shape function, which could give more information on transfer time utility contribution. The results of the model performance and parameter estimates are detailed in Table 7.7 and Appendix D respectively.

Table 7.7: Comparison of the model performances when transfer time non-linearity is included

Model	**Likelihood ratio test**	**AIC**	**BIC**	**Adjusted** ρ^2
Generic model	2088.297	3135.406	3194.671	0.3972
Transfer time (sq and cu)	2094.31	3133.393	3203.434	0.3976
Transfer time (sq)	2088.661	3137.042	3201.695	0.3969
Transfer time (sq and cu), no lift	2094.285	3131.418	3196.07	0.3980

The model assessing the non-linearity of the transfer time parameter using only the quadratic term resulted in a decrease in the model performance, with higher AIC and BIC values than the base model and a decrease of the value of the adjusted rho-square. Furthermore, the quadratic component was found to not be highly significant, with a p-value of 0,55. However, in the model where both the quadratic and the cubic terms were included, both parameters were found to be highly significant with p-values lower than 0.03. This model also showed a performance improvement based on a smaller AIC than the base model, although the BIC value slightly increased due to the added complexity in the model. A trade-off is here made between the high significance of the parameters and the increase in the complexity of the model, as well as a trade-off between this complexity increase and the interpretation of the model. It is then decided to include both the quadratic and cubic parameters in the base model, besides the increase of the model complexity, because of the high significance of the parameters as well as the wish in this study to highlight the travel time non-linearity.

Further improvements to the model's performance can be achieved by removing the least significant parameters. To minimise the number of parameters removed and not reduce too much the explanatory power of the model, only the least significant parameter, the parameter of the dummy representing the transfer type cross-station with lift, was removed from the base model. The model performance results of this model are also visible in Table 7.7. This adjustment led to improvements in terms of AIC and adjusted rho square compared to both the base model and the model incorporating quadratic and cubic transfer time parameters with the lift dummy. However, although the BIC value is found to be higher than that of the base model, it showed a significant reduction compared to the BIC of the model with non-linear transfer time parameters. Therefore, this new model was chosen as the final base model.

Final MNL model
As discussed previously, the final MNL model includes all the attributes from the survey, except the category cross-station with lift from the transfer type attribute. Furthermore, the model accounts for the non-linearity of the transfer time attribute, by incorporating both a quadratic and a cubic parameter. The updated utility function for the Transfer 1 alternative is given in Equation 7.6, with the additional terms highlighted in red. The utility function for the Transfer 2 alternative is updated similarly.

$$
\begin{aligned}
V_{transfer1} = {} & \beta_{tt} \cdot tt_{transfer1} + \beta_{tc} \cdot tc_{transfer1} + \beta_{transfertime\_transfer} \cdot transfertime\_transfer1 \\
& + \beta_{transfertime\_transfer\_sq} \cdot transfertime\_transfer1\_sq \\
& + \beta_{transfertime\_transfer\_cu} \cdot transfertime\_transfer1\_cu \\
& + \beta_{delay\_transfer} \cdot delay\_transfer1 \\
& + \beta_{Escalator\_transfer} \cdot Escalator\_transfer1 + \beta_{Stairs\_transfer} \cdot Stairs\_transfer1 \\
& + \beta_{frequency\_transfer} \cdot Dummy\_frequency\_transfer1
\end{aligned} \tag{7.6}
$$

Where
$\beta_{transfertime\_transfer\_sq}$ is the quadratic parameter of transfer time
$\beta_{transfertime\_transfer\_cu}$ is the cubic parameter of transfer time
$transfertime\_transfer1\_sq$ is the quadratic value of transfer time
$transfertime\_transfer1\_cu$ is the cubic value of transfer time

The parameter estimates resulting from this model are summarised in Table 7.8.

Table 7.8: Parameter estimates of the final base model

Parameters	Value	Rob. Std err	Rob. t-test	Rob. p-value
ASC_car	2.312	0.368	6.291	3.154×10^{-10}
ASC_directtrain	2.850	0.336	8.477	0
ASC_plane	2.472	0.352	7.017	2.275×10^{-12}
B_Escalator_transfer	-0.872	0.182	-4.783	1.726×10^{-06}
B_Stairs_transfer	-0.196	0.1655	-1.182	0.237
B_delay_transfer	-0.025	0.013	-1.917	0.055
B_frequency_transfer	-0.086	0.140	-0.616	0.538
B_tc	-0.061	0.003	-23.673	0
B_transfertime	0.037	0.007	4.963	6.928×10^{-07}
B_transfertime_cu	-6.083E-05	2.383E-05	-2.552	0.011
B_transfertime_sq	0.003	0.001	2.608	0.009
B_tt	-0.017	0.001	-16.698	0

MNL model with socio-demographics and travel habits interactions
Interactions between socio-demographic characteristics and travel habits with the study attributes were tested to gain insights into personal characteristics influencing behaviour and to improve the model fitting to the data. Socio-economic characteristics and travel habits collected from the respondents were tested as interaction with the attributes, both specifics and generics, focusing on interactions that could potentially be significant. Interactions were selected for inclusion in the final base model based on significant improvement in model fit indicators such as the Akaike Information Criterion (AIC), the Bayesian Information Criterion (BIC), and the adjusted R-square. Additionally, interactions were considered based on their parameter significance level. Trade-offs were made between including significant interaction parameters and maintaining model parsimony.
It is important to remember that findings are specific to leisure travel over distances of approximately 500 kilometres. In other contexts, such as business travel, different interactions may be found significant, as indicated in the existing literature.

To incorporate socio-demographic characteristics and travel habits into the model, these variables were dummy-coded. The specific dummy coding used is detailed in Appendix E. For gender, age, driving license status and railway transfer experience, the reference categories are 'Male', '18 to 30 years old','Yes' and 'Yes' respectively. Additionally, some categories were aggregated or excluded from testing to ensure that each category had at least 30 respondents, which is necessary for obtaining statistically significant results. The ages were aggregated into two broader categories, and for the income, the category representing incomes over 100.000€ was excluded due to insufficient respondents. Regarding occupation, only students and full-time workers were included in the analysis, as the other occupational categories had too few respondents. Similarly, the category of travellers who rarely or never travel was not tested due to its small sample size.

Socio-demographics
Gender was tested as an interaction with travel time, travel cost, transfer time, delay, frequency, transfer type (stairs and escalator) and the alternative specific constant ASC for car. These interactions were explored to capture potential gender differences in the perception of time, cost, and the challenges associated with platform change with luggage, as well as a potential preference to avoid public transport. Among these interactions, the one with travel cost, transfer time and delay were found to be the most significant and led to the best model improvement compared to the other interactions.

Age interactions were tested with travel time, travel cost, transfer time, ASCs and transfer type (stairs and escalator). With these interactions, potential differences in time and cost perception, preferences to avoid transfer and walking during transfer for older respondents were tested. Travel cost, travel time, escalator and ASC direct plane interaction with age resulted in significant parameters within a 5% confidence interval. Furthermore, almost all interactions tested had an increase in model fit according to their AIC and adjusted rho square except for interactions with the transfer type with the escalator and the ASC for car. However, only the ASC direct train interaction parameter had a BIC value smaller than the base model. To balance model performance and complexity, only this interaction parameter will be kept.

Driving license was only tested as interaction with the ASC for car, as having a driving license could give an initial preference for the car alternative. Despite the interaction parameter being highly significant, it did not improve model performance and will not be included in the final model.

For the respondents' *current occupation*, for both student and full-time workers, travel time and travel cost interactions were tested due to possible differences in time and cost perceptions compared to the rest of the sample. For students, the travel cost interaction parameter was highly significant and improved model fit, while the travel time interaction was less significant and increased the BIC value compared to the base model. For full-time workers, the opposite was observed, with travel time interaction significantly improving the model and travel cost interaction decreasing model performance.

Similarly, travel time and travel cost interactions were tested for the four remaining *income* categories, as cost and time could be perceived differently based on earnings. For a gross annual household income of less than 10.000€, the travel time interaction was found to be highly significant and to improve the model performance, whereas travel cost did not. Therefore, only the travel time interaction will be kept for this category. For incomes between 10.000€ and 30.000€, both travel time and travel cost interactions were found highly significant at the 5% confidence interval, but only travel cost improved the model performance. For incomes between 30.000€ and 50.000€, neither interaction parameter was found to be significant, and they did not contribute to model improvement, so no interactions will be added for this category. For incomes between 50.000€ and 100.000€, both interaction parameters were found to be highly significant, but only travel cost interaction improved the model performance. Thus, only travel cost interaction will be included in the model.

Travel habits
The *usual mode* taken for international long-distance travel in Europe was tested as an interaction with the ASCs, as prior experience with a specific mode could increase its initial utility, independent of other attributes. Including interactions with the ASC for plane and ASC for car resulted in highly significant parameters and a notable improvement in model performance.

Railway transfer experience was tested as interaction with all specific and generic attributes, as prior experience with railway transfers could influence perceptions of key attributes, such as transfer-related factors and initial mode preference. Six interactions: travel cost, transfer time, delay, transfer frequency, ASC plane, and ASC car, resulted in highly significant parameters and an increase in the base model performance. Although interactions with delay, frequency, and the ASCs showed slightly higher BIC values, they will be retained to observe their behaviour in the complete model.

Finally, the *travel frequency* interaction to attributes was assessed. Only interactions with travel time, travel cost, and ASCs were considered, as travel frequency could affect the willingness to pay, the perception of travel time, and the initial mode preference. For annual travellers, no interaction parameter was found to be highly significant or to improve model performance. For occasional travellers (2 to 3 times a year), the travel cost interaction parameter was significant but did not enhance the model. For regular travellers (4 to 5 times a year), no interaction parameter improved the model or showed high significance. For frequent travellers (more than 5 times a year), the ASC direct train interaction was found to be highly significant and to improve the model performance.

Table 7.9: Interactions included in the first model with socio-demographics and travel habits

	Attributes									
	Travel cost	*Travel time*	*Transfer time*	*Delay*	*Escalator*	*Stairs*	*Frequency*	*ASC car*	*ASC train*	*ASC plane*
Gender	X		X	X						
Age									X	
Driving license										
Student	X									
Full-time		X								
Income less than 10k		X								
Income 10 to 30k	X									
Income 30 to 50k										
Income 50 to 100k	X									
Transfer experience	X		X	X			X	X		X
Usual mode								X		X
Travel annual										
Travel occasional										
Travel regular										
Travel frequent									X	

In total, 18 interaction parameters between the attributes and socio-demographics or travel habits were found to be highly significant and/or to improve the base model performance. These interactions are summarised in Table 7.9. They were all added to the base model and a new model was estimated. The results, including the model performance and the parameter estimates, are visible in Appendix E. This new model is leading to a strong increase in the model fit compared to the previous base model, with a likelihood ratio test increasing from 2094,285 to 2261,863, an AIC and BIC decreasing from 3131,418 to 2997,84 and from 3196,07 to 3154,084 respectively, as well as an important increase of the adjusted rho-square from 0,398 to 0,424.
To simplify the model and avoid over-fitting, eight interaction parameters that were not highly significant, represented by a higher p-value, or that did contribute to a lesser extent to the improvement of the model performance, were removed from that model. These interactions are transfer experience with delay, frequency, travel cost and transfer time, full-time workers with travel time, students with travel cost, gender with delay and income from 50.000€ to 100.000€ with travel cost.

A final model is then computed with the remaining interactions. Its performance and parameter estimates are shown in Table 7.10 and Table 7.11 respectively. Overall, the model performs better than the previous one, with lower AIC and BIC values, and a higher rho-square value.

To complete the analysis of the model's results, the utility contribution of the parameters quantified in

Table 7.10: Performance of base model with added socio-demographics and travel habits interactions

Model	Likelihood ratio test	AIC	BIC	Adjusted rho square
Base + Socio-demographics and travel habits	2255.092	2990.611	3109.141	0.4251

Table 7.11: Parameter estimates of the model including the socio-demographic and travel habits interactions

Parameter	Value	Rob. Std err	Rob. t-test	Rob. p-value
ASC_car	2.750	0.426	6.462	0.000
ASC_car_Exp	-0.864	0.283	-3.057	0.002
ASC_car_ModeCar	0.910	0.291	3.128	0.002
ASC_directtrain	2.681	0.351	7.641	0.000
ASC_directtrain_Age	0.472	0.160	2.956	0.003
ASC_directtrain_f	0.432	0.167	2.595	0.010
ASC_plane	1.783	0.457	3.899	0.000
ASC_plane_Exp	-0.278	0.228	-1.219	0.223
ASC_plane_ModePlane	1.373	0.218	6.292	0.000
B_Escalator_transfer	-0.911	0.190	-4.8011	0.00
B_Stairs_transfer	-0.218	0.168	-1.303	0.193
B_delay_transfer	-0.027	0.014	-1.995	0.046
B_frequency_transfer	-0.100	0.140	-0.716	0.474
B_tc	-0.055	0.004	-15.475	0.000
B_tcExp	-0.006	0.003	-1.997	0.046
B_tcIncome1030	-0.013	0.004	-3.441	0.001
B_transfertime	0.045	0.008	5.664	0.000
B_transfertime_cu	-6.084E-05	0.000	-2.524	0.012
B_transfertime_sq	0.003	0.001	2.633	0.008
B_transfertime_transferGender	-0.0160	0.004	-3.618	0.000
B_tt	-0.018	0.001	-17.205	0.000
B_ttIncome10	0.004	0.001	3.353	0.001

time and cost, is measured. This will allow to understand which attributes are influencing the most the utility and how their impact varies through the attribute range studied. These utility contributions are presented in Table 7.12.

First of all, the initial preferences of travellers for specific mode and their dispreferences for transfers are estimated. The alternative specific constants (ASCs) parameters provide insights into these preferences, capturing traveller choices aspects that are not fully explained by the observed variables in the model. In this study, the baseline mode considered is the train with transfer alternatives, against which the preferences for the other modes are compared. The ASCs for car, plane, and direct train are all highly significant, as illustrated by robust t-tests and p-values. Each ASC value is positive and high, ranging between 1.78 and 2.75. This indicates strong initial preferences for these modes over the train with transfer alternative, assuming all other attributes are null for the train wit transfer alternatives. Among these, the direct train and the car have the highest ASC values, suggesting they are the most preferred options. These findings suggest that travellers have a marked preference for direct travel potions, possibly due to the aversion to the inconvenience associated with railway transfers or transfers in general.

The preference for direct routes is quantified by measuring how much travellers are willing to pay to avoid rail travel with transfers, comparing it to car and plane, and avoiding the transfer only when compared to direct train. The results of the willingness-to-pay (WTP) analysis are presented in Table 7.15.
Travellers are ready to pay 49,58€ to travel by car instead of train with a transfer, and 32,16€ to travel

Table 7.12: Utility contribution of time and cost related attributes and interactions

Parameter	Unit	Value	Attribute range	Min utility contribution	Max utility contribution	Difference
B_delay_transfer	utils/min	-0,0270	2 - 11	-0,0540	-0,297	0,243
B_transfertime	utils/min	0,0449	10 - 40	0,449	1,794	1,346
B_transfertime_cu	utils/min^2	-0,0000608	10 - 40	-0,000608	-0,00243	0,002
B_transfertime_sq	utils/min^3	0,00281	10 - 40	0,0281	0,112	0,084
B_transfertime + B_transfertime_cu + B_transfertime_sq	-	-	-	0,4760	1,904	1,428
B_transfertime_ transferGender	utils/min	-0,0160	10 - 40	-0,1595	-0,638	0,479
B_tt	utils/min	-0,0181	210 - 405	-3,8026	-7,334	3,531
B_tc	utils/euro	-0,0555	30 - 125	-1,6637	-6,932	5,268
B_tcExp	utils/euro	-0,0062	30 - 125	-0,1852	-0,772	0,587

Table 7.13: Willingness to pay for another mode to avoid railway transfer

	Car	Direct train	Plane
WTP (€)	49,58	48,34	32,16

by plane instead of train with transfer. Moreover, they are willing to pay 48,34€ to avoid to have a transfer during their train journey. These findings illustrate that travellers are willing to pay more to avoid railway transfers if they have the possibility to travel by car, compared to when plane travel is an option, Furthermore, the willingness to pay to avoid transfers is similar when choosing car travel and when opting for direct train routes.

Significant interactions are found between socio-demographics, travel habits and the ASCs, illustrating heterogeneity in the initial modal preference and the degree of transfer aversion. For the ASCs of car and plane, previous experience with railway transfers reduces the initial utility of choosing to travel by car or by plane, with a more pronounced effect for cars. This suggests that individuals who have previously experienced a railway transfer during an international long-distance trip in Europe are less likely to have a strong initial preference for using cars or planes compared to those who never had an experience with railway transfers. This could indicate that these travellers have overcome any apprehension about railway transfers and now perceive them as a more acceptable than travellers that never experienced it. Oppositely, habitual use of cars and planes for these types of travel significantly increases the initial preference for these modes, compared to train with transfer. This could reflect a stronger aversion to the perceived inconveniences of railway transfers, such as additional time and effort, particularly among those accustomed to car and plane travel, opposed to travellers already using rail for this type of trips. Furthermore, older individuals, aged over 30 years and frequent travellers show a higher initial preference for direct trains compared to train with transfers.

Next, the results regarding the impact of the transfer-related attributes are analysed and a more concrete interpretation of these findings is given. The utility coefficient (betas) for all attributes show the expected signs. Travel time, travel cost, delay, frequency, and cross-station transfer with escalator or stairs parameters all have negative coefficients indicating a negative contribution to utility. In contrast, transfer time has a positive coefficient, showing a positive contribution to utility. More detailed interpretations of the parameter values and their significance are provided below.

The travel time parameter is highly significant and has a large negative value, indicating a strong negative impact on utility. This suggests that longer travel times substantially reduce the attractiveness of a mode. This is confirmed by the utility contribution ranging from -3.51 to -6.77 utils for a travel time range of 210 to 405 minutes. Furthermore, individuals with an annual gross household incomes lower than 10.000€ are found to be less sensitive to travel time, as indicated by the positive and significant interaction parameter between travel time and low income. This means that the total disutility of travel time is lower for this category of travellers. Their lower income could push them to trade-offs between travel time and travel costs and they could choose higher travel times if it means having lower travel costs.

The travel cost parameter is also highly significant and has a large negative value, meaning that higher travel costs significantly decrease utility. The large utility contribution decrease in the travel cost from 30 to 125 euros also highlights travel cost as being an important factor in mode choice. Travel cost is found to have the most significant negative impact on utility, followed closely by travel time, suggesting that the travellers are more sensitive to cost than to time when making their travel decisions. It could also be noted that sensitivity of travellers to travel cost and time could be specific to the mode chosen, as illustrated by the significant alternative specific travel time and travel cost that where estimated but not included in the final MNL model, for model simplicity purpose. Additionally, individuals with a previous railway transfer experience and those with lower annual gross household income, between 10.000€ and 30.000€, exhibit greater sensitivity to travel costs. This is evidenced by their significant and negative interaction parameters which suggest that the disutility of travel costs is more pronounced for these groups. For individuals with lower incomes, even small differences in travel costs could have a significant impact on their mode choice, making them more likely to opt for options that minimise costs, even if it means having to transfer. Those with previous railway transfer experience may perceive transfers as a manageable inconvenience, especially if it leads to significant cost savings.

Transfer time emerges as one of the most significant parameters and with a positive value suggesting that longer transfer times increase the travellers preference for a transfer. This could be due to the perceived benefits of having time to transfer more comfortably and not miss a connection, as well as reducing stress levels associated with railway transfer which has been highlighted in the previous chapter. However, the statistically significant quadratic and cubic terms of transfer time are indicating that the relation between the transfer time and the utility contribution is non-linear. As illustrated in Figure 7.5, the utility of transfer time increases at a decreasing rate between 20 and 30 minutes compared to the increase observed between 10 and 20 minutes. This increase rate in utility further slows down between 30 and 40 minutes of transfer time. This non-linear relationship suggests that while additional transfer time initially adds value, the utility gain diminishes as transfer time continues to increase.

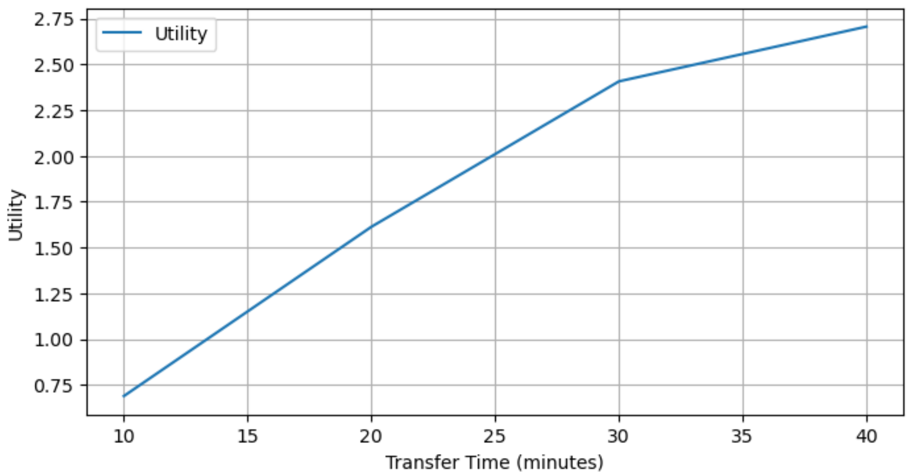


Figure 7.5: Utility contribution of transfer time

An increase in the potential average delay of the first train before a transfer is associated with a significant decrease in utility, as indicated by the negative and highly significant parameter.This result reflects that travellers perceive higher delays negatively, as it impacts their overall travel experience. In case of delay of the first train, the transfer time is reduced, which could potentially lead to a missed connection an to an increase of the total travel time, which could push the travellers to choose a different transport mode to avoid to be confronted to this situation. The utility contribution of the delay parameter is smaller compared to other time-related parameters, This is primarily due to the limited range of the delay attribute, which spans only 9 minutes. The model considers average delay rather than maximum delay, which might account for the relatively smaller impact on utility.

This aversion for transfers can be seen through the travellers different perception of different transfer-related attributes, in comparison to total travel time. The respondents are found to value one additional minute of transfer time and one additional minute of delay of the first train as more impactful than one minute of total travel time. The ratios illustrating these perceptions are provided in Table 7.14.

Table 7.14: Total travel time equivalent of transfer time and delay

Transfer Time Ratio	Delay Ratio
2,48	1,49

The findings reveal that travellers perceive an additional minute of transfer time as equivalent to approximately 2.5 minutes of total travel time, and an additional minute of delay on the first train as equivalent to about 1.5 minutes of total travel time. This suggests that travellers find transfer time to bring more significant disutility compared to delays on the first train. Furthermore, the results show that female travellers are more sensitive to transfer time increase than male travellers. Due to the negative interaction parameter value, the positive utility contribution of transfer time for females is reduced to 0.0289, compared to 0.0449 for the full sample.

Regarding transfer type, cross-station with escalator and cross-station with stairs both show negative values, indicating that platform change is disliked by traveller. Preference for cross-platform transfer could be associated with less walking for example. However, the analysis shows that the coefficient for transfers involving escalators is more negative and statistically significant compared to stairs. This suggests that the use of escalators is seen as playing a higher role in the dispreferred for cross-station transfer.

The penalty associated with a cross-station transfer, as opposed to a cross-platform is estimated. Since the use of lifts for platform change was removed from the model and the use of stairs was not considered highly significant by travellers, the category ”cross-station with escalator” is used to represent the overall cross-station category. The cross-station penalty is calculated based on the transfer time penalty, determining the equivalent additional transfer time perceived when travellers have to change platforms. Additionally, the penalty for changing platforms is calculated in monetary terms, reflecting how much travellers are willing to pay to avoid a transfer that involves changing platforms. The results of this cross-platform penalty are given in Table 7.15.

Table 7.15: Transfer time and cost equivalent penalty of cross-station transfer

	Transfer time penalty (min)	Cost penalty (€)
Cross-station transfer	20,30	16,42

The results indicate that a cross-station transfer is associated with a transfer time penalty equivalent to 20.3 minutes and a cost penalty of 16.42€. This means that travellers perceive the inconvenience of changing platforms as equivalent to adding an extra 20.3 minutes to their transfer time. Additionally, they are willing to pay 16.42€ to avoid a cross-station transfer. These findings highlight the significant penalty and inconvenience associated with changing platforms.

The results of the model also indicate that a decrease in the frequency of the second train at the transfer station negatively impacts the utility, Specifically, utility decreases by 0.1 utils when the frequency drops from one train every hour to one train every two hours. This suggests that travellers have a preference for higher train frequencies at stations. This decrease in utility associated with lower frequency could be due to the inconvenience of longer waiting times if a connection is missed, with waiting an additional hour or more being seen as a drawback for travellers. This was illustrated earlier with the negative significant interaction parameter between transfer time and frequency of the second train. However, the frequency parameter p-value of 0.457 indicates that this parameter is not found to be highly significant. This implies that, while higher train frequency might be preferred, its influence on mode choice is not as strong as other factors in the model.

The updated utility functions of the five alternatives are given below.

$$\begin{aligned} V_{transfer1} = {} & \beta_{tt} \cdot tt_{transfer1} + \beta_{tc} \cdot tc_{transfer1} + \beta_{transfertime\_transfer} \cdot transfertime\_transfer1 \\ & + \beta_{transfertime\_transfer\_sq} \cdot transfertime\_transfer1\_sq + \beta_{transfertime\_transfer\_cu} \cdot transfertime\_transf \\ & + \beta_{delay\_transfer} \cdot delay\_transfer1 \\ & + \beta_{Escalator\_transfer} \cdot Escalator\_transfer1 + \beta_{Stairs\_transfer} \cdot Stairs\_transfer1 \\ & + \beta_{frequency\_transfer} \cdot Dummy\_frequency\_transfer1 \\ & + \beta_{transfertime\_transferGender} \cdot transfertime\_transfer1 \cdot Gender \\ & + \beta_{ttIncome10} \cdot tt\_transfer1 \cdot Income\_10k \\ & + \beta_{tcIncome1030} \cdot tc\_transfer1 \cdot Income\_1030k \\ & + \beta_{tcExp} \cdot tc\_transfer1 \cdot Railway\_transfer\_experience \end{aligned} \quad (7.7)$$

$$\begin{aligned} V_{transfer2} = {} & \beta_{tt} \cdot tt_{transfer2} + \beta_{tc} \cdot tc_{transfer2} + \beta_{transfertime\_transfer} \cdot transfertime\_transfer2 \\ & + \beta_{transfertime\_transfer\_sq} \cdot transfertime\_transfer2\_sq + \beta_{transfertime\_transfer\_cu} \cdot transfertime\_transf \\ & + \beta_{delay\_transfer} \cdot delay\_transfer2 \\ & + \beta_{Escalator\_transfer} \cdot Escalator\_transfer2 + \beta_{Stairs\_transfer} \cdot Stairs\_transfer2 \\ & + \beta_{frequency\_transfer} \cdot Dummy\_frequency\_transfer2 \\ & + \beta_{transfertime\_transferGender} \cdot transfertime\_transfer2 \cdot Gender \\ & + \beta_{ttIncome10} \cdot tt\_transfer2 \cdot Income\_10k \\ & + \beta_{tcIncome1030} \cdot tc\_transfer2 \cdot Income\_1030k \\ & + \beta_{tcExp} \cdot tc\_transfer2 \cdot Railway\_transfer\_experience \end{aligned} \quad (7.8)$$

$$\begin{aligned} V_{directtrain} = {} & ASC_{directtrain} \\ & + ASC_{directtrain\_Age} \cdot Age \\ & + ASC_{directtrain\_f} \cdot Travel\_Frequent \\ & + B_{tt} \cdot tt\_train + B_{tc} \cdot tc\_train \\ & + B_{ttIncome10} \cdot tt\_train \cdot Income\_10k \\ & + B_{tcIncome1030} \cdot tc\_train \cdot Income\_1030k \\ & + B_{tcExp} \cdot tc\_train \cdot Railway\_transfer\_experience \end{aligned} \quad (7.9)$$

$$\begin{aligned} V_{plane} = {} & ASC_{plane} \\ & + ASC_{plane\_Exp} \cdot Railway\_transfer\_experience \\ & + ASC_{plane\_ModePlane} \cdot Use\_Plane \\ & + B_{tt} \cdot tt\_plane + B_{tc} \cdot tc\_plane \\ & + B_{ttIncome10} \cdot tt\_plane \cdot Income\_10k \\ & + B_{tcIncome1030} \cdot tc\_plane \cdot Income\_1030k \\ & + B_{tcExp} \cdot tc\_plane \cdot Railway\_transfer\_experience \end{aligned} \quad (7.10)$$

$$
\begin{aligned}
V_{car} = {} & ASC_{car} \\
& + ASC_{car\_Exp} \cdot Railway\_transfer\_experience \\
& + ASC_{car\_ModeCar} \cdot Use\_Car \\
& + B_{tt} \cdot tt\_car + B_{tc} \cdot tc\_car \\
& + B_{ttIncome10} \cdot tt\_car \cdot Income\_10k \\
& + B_{tcIncome1030} \cdot tc\_car \cdot Income\_1030k \\
& + B_{tcExp} \cdot tc\_car \cdot Railway\_transfer\_experience
\end{aligned}
\tag{7.11}
$$

7.2.2. Mixed Panel Logit Model

A mixed panel logit model is developed to account for panel effect and the possible heterogeneity of traveller preferences. As each respondent contributed to eight observations, panel effect should be included as the first observations will bring more information and contribute more to the parameter estimation than the subsequent choices of a same respondent. To not account for panel effect could lead to an overestimation of the parameters, which mean an overestimation of the observed effect of the attributes on utility. Furthermore, making parameters random allow to account not only for the mean effect but also the standard deviation of the effect, allowing to see if heterogeneity exist in preferences and the impact of the parameters.
First, different panel ML models were estimated by randomising all parameters one by one. Their mean and standard deviation significance and values were observed to see if the contribution of the utility of the attributes is the same for all the travellers. The code used for the ML model is provided in Appendix F. Heterogeneity in preferences was observed through significant standard deviation parameters for the following attributes: the ASCs, escalator, frequency, delay and transfer time. These randomised parameters were then all combined into a single model to obtain the final ML model. In this model, the lift parameter, as well as the square and the cubic terms of the transfer time were removed, as they were found to be non-significant in all the ML models estimated. The results of this model, with the estimated parameter values and the model fit data are given in F.
The results are showing that only the standard deviation parameters of the ASCs are still highly significant and no heterogeneity is observed for the transfer-related attributes. Two new models were then estimated, a model with only the randomised ASCs, and a second model with the transfer-related parameter randomised. The results of these models are respectively given in Table 7.16 and Table 7.17.

The results of the model with the ASCs randomised show that all travellers do not hold the same preferences for the same modes or the same initial dispreference for railway transfer. Furthermore, the model with the transfer-related attributes also illustrated that all travellers are not impacted in the same way by these attributes. The highest value for standard deviation is in this model associated with the frequency of the second train, showing that there is more variability in the impact of this specific attribute on the utility, than for the other attributes. The same thing applies to the ASCs model, where the ASCs of car and plane have highly significant standard deviation values, illustrating the diversity in the initial preferences for these modes compared to train with transfer.

Finally, the model fit of these two models was compared to the model fit of the MNL model including socio-demographics and travel habits interactions in Table 7.18 . With a significant higher likelihood ratio test and adjusted rho square than the two other models, as well as a significant lower AIC and BIC, the model with all the ASC randomised was found to be the best fitted to the data. This model will then be used in the model application in the next sub-section.

7.2.3. Model application

In this sub-section, different scenarios are applied to the model to see how changes in the alternative characteristics are impacting the market share.

Four different scenarios are applied and compared to a base model to notably see the impact of changes in the values of transfer type, travel cost and frequency of the second train. The base scenario consid-

Table 7.16: Parameter estimates of the model including all the AScs as random

Parameter	Value	Rob. Std err	Rob. t-test	Rob. p-value
ASC_car	0.245	0.531	0.460	0.645
ASC_car_std	-2.532	0.388	-6.529	0.000
ASC_directtrain	2.356	0.262	8.998	0.000
ASC_plane	0.362	0.491	0.736	0.462
ASC_plane_std	-3.215	0.351	-9.168	0.000
ASC_train_std	-1.199	0.274	-4.383	0.000
ASC_transfer_std	0.872	0.324	2.693	0.007
B_Escalator_transfer	-0.783	0.197	-3.966	0.000
B_Stairs_transfer	0.153	0.165	0.928	0.353
B_delay_transfer	-0.042	0.015	-2.859	0.004
B_frequency_transfer	-0.279	0.135	-2.066	0.039
B_tc	-0.076	0.007	-20.744	0.000
B_transfertime	0.036	0.006	5.671	0.000
B_tt	-0.019	0.001	-14.447	0.000

Table 7.17: Parameter estimates of the model including the escalator, frequency, delay and transfer time as random parameters

Parameter	Value	Rob. Std err	Rob. t-test	Rob. p-value
ASC_car	2.835	0.423	6.709	0.000
ASC_directtrain	3.208	0.345	9.286	0.000
ASC_plane	2.937	0.416	7.063	0.000
B_Escalator_transfer	-0.884	0.241	-3.677	0.000
B_Escalator_transfer_std	-0.591	0.385	-1.536	0.125
B_Stairs_transfer	0.207	0.167	1.241	0.215
B_delay_transfer	-0.047	0.0171	-2.761	0.006
B_delay_transfer_std	-0.096	0.024	-3.911	0.000
B_frequency_transfer	-0.070	0.133	-0.524	0.599
B_frequency_transfer_std	1.035	0.228	4.547	0.000
B_tc	-0.080	0.005	-16.848	0.000
B_transfertime	0.049	0.008	5.975	0.000
B_transfertime_transfer_std	-0.042	0.006	-6.539	0.000
B_tt	-0.021	0.002	-12.630	0.000

ered is for a travel time of 5h30, a travel cost of 90€, cross-platform transfer, with an average possible delay of the first train of 5 minutes, 30 minutes transfer time and a frequency of the second train of a train every hour. For the other alternatives, travel time and cost are fixed to the same values as in the survey. The results of the scenario variation are summarised in Table 7.19. In the results, the variation in market share is more important for the analysis than the market share values themselves, as we want to measure the impact of the variation of different attributes in the market share.

Scenario 1: Cross-station transfer
In this first scenario, the transfer type is changed from cross-platform to cross-station with an escalator available, considered here as representing a cross-station transfer. The results show an important decrease in the market share for trains with a transfer, a significant increase in the market share for direct train and a small increase for plane and car. This shows that having to change platforms is a strong deterrent for travellers and an important part of the travellers would prefer a direct connection to avoid having to change platforms. This indicates that operators should focus on providing transfers on the same platform, especially on popular transfer routes.

Scenario 2 and 3: Travel cost incentive and penalty
In these two scenarios, cost incentives and cost penalties are applied to stimulate a market share

Table 7.18: Model fit comparison between the final MNL model and the two ML models

Model	Likelihood ratio test	AIC	BIC	Adjusted rho square
Final MNL	2255,092	2990,611	3109,141	0,4251
ML with ASC random	2582,106	2647,594	2693,91	0,4910
ML with 4 random attributes	2249,594	2980,106	3026,421	0,4270

change and see which one will be more efficient to increase rail market share and reduce plane use. In scenario 2, a reduction of 15€ is applied to the train with a transfer option in comparison to the base scenario. This could be the equivalent of having a reduction of 15€ for each transfer included in a rail journey. In scenario 3, the travel cost of the plane alternative is increased by 15€ compared to the base scenario. This could be seen as a penalty that could be applied to plane journeys, like a carbon tax. Decreasing the travel cost of the train with the transfer option is seen as efficient for stimulating market share change. However, this measure will mostly attract travellers already using the train but direct option, and penalty for the plane is more efficient to stimulate a decrease in the market share of planes.

Scenario 4: Frequency at transfer point
In this scenario, the frequency of the second train is fixed to one every two hours, compared to one every hour in the base scenario. This decrease in frequency could stimulate a shift of travellers from train with transfer to direct train but also plane and car to a lesser extent. This could be linked to travellers being afraid to wait too long in case of a missed connection. Railway operators should then optimise transfers, by, for example, having the connecting trains waiting for possible delayed trains to avoid missed connections, if increasing train frequency is not possible.

Table 7.19: Market shares for different scenarios compared to base scenario

	Train with transfer		**Direct train**		**Plane**		**Car**	
	%	% diff	**%**	% diff	**%**	% diff	**%**	% diff
Base scenario	74,9		22,2		2,4		0,5	
Scenario 1	58,3	**-16,6**	36,9	**+14,7**	4	**+1,6**	0,8	**+0,3**
Base scenario	74,9		22,2		2,4		0,5	
Scenario 2	90,1	**+15,2**	8,8	**-13,4**	0,9	**-1,5**	0,2	**-0,3**
Scenario 3	76,1	**+1,2**	22,6	**+0,4**	0,8	**-1,6**	0,5	**0**
Base scenario	74,9		22,2		2,4		0,5	
Scenario 4	69,4	**-5,5**	27	**+4,8**	3	**+0,6**	0,6	**+0,1**

8

Conclusion and discussion

In this chapter, the conclusion of the research is given by answering the different research questions. The results are discussed and recommendations are given.

8.1. Conclusion

The goal of this research was to gain insights into the preferences of long-distance travellers in Europe, when a transfer is included in their railway journey, to gain more knowledge on the impact of railway transfers in mode choice for leisure trips. This is important to have a deeper understanding of what could be more attractive for railway travellers in transfers, to stimulate a shift from less sustainable modes such as planes and cars, to railway when a direct rail route is not always available. Studies on transfers have been mostly focused on urban multimodal transfer or long-distance plane transfer, where travellers could have different preferences than in railway transfer in their long-distance international trips. The main research question resulting from this objective was defined as:

To what extent do railway transfers impact passenger mode choice in long-distance leisure travel in Europe and what are the associated penalties and preferences associated with railway transfers?

To answer to the main research question, sub-questions were formulated and that will be answered here.

Sub-research question 1: Which attributes or elements do travellers consider important in a route including a transfer in long-distance travelling?
A literature review was conducted on current research on travel behaviour in relation to transfers and complemented by traveller interviews, to identify the key elements that travellers consider important if they have to transfer on their route. The literature review provided insights for different contexts than the current study, including short-distance travelling and multimodal transfers, as well as long-distance air travel connections. While these studies highlight important attributes, the intensity of their importance may vary due to differences in distance and travel modes. The interviews focused on a similar context to the study, long-distance international travel in Europe with railway transfers. Regarding the elements related to the overall journey, travel time and travel cost were emphasized as important, both in the literature review and in the interviews, in travellers mode and route choice. For attributes and elements directly related to the transfer in itself and not the overall trip, transfer time, the uncertainty of arriving on-time at the transfer and missing the connection, as well as the transfer type were all considered as important. The influence of transfer time was found to be non-linear and varies based on the distance of the trip and the mode involved in the transfer. The uncertainty of arriving on-time at the transfer linked to a possible missed connection was found to be an important concern for travellers in the interviews. This concern was balanced by the frequency of the second train, with fewer concerns about a delay of the first train and a short transfer time if the connection was frequent. Furthermore, the impact of transfer type such as cross-station transfer in comparison to cross-platform transfer, was

found to potentially influence preference for routes with transfer. Finally, stress and anxiety related to railway transfers emerged prominently in the interviews., linked to other possible elements such as missed connection. These elements found were accounted for in the rest of the study to create the choice experiment. add attitudes there

Sub-research question 2: Is there an initial dispreference for railway transfers in long-distance leisure travel, and if yes, to what extent?
The results were obtained by analyzing the results of a stated preferences survey, using a multinomial logit model (MNL). The attributes in the choice experiment, derived from the answer to the first sub-question, included door-to-door travel time, door-to-door travel cost, transfer time, potential delay of the first train, frequency of the second train, and transfer type.
When considering overall preferences and dispreferences for railway transfer, strong initial preferences were observed for using plane, car and direct train over train with transfer. This is shown by the high values of the alternative specific parameters for car, plane and direct train, as well as the willingness to pay (WTP) to avoid a train transfer when only the initial preference for a mode is considered. Travellers are willing to pay approximately 50€ to avoid a train transfer when car travel is available, around 32€ if plane travel is an option and around 48€ to avoid a transfer when a direct rail route is available. Furthermore, the initial contribution to utility for car and plane is higher if these modes are the primary means of travel for respondents for similar journeys. However, this initial preference for car and plane diminishes when travellers have prior experience with railway transfers. This suggests that a portion of the initial disutility associated with rail transfers could be linked to apprehension or stress at the idea of having to do a transfer. Additionally, the initial preference for direct train and desire to avoid transfers increases with age and are more pronounced among frequent travellers, defined in this study as travellers making these kinds of trips at least five times a year, not necessarily related to experience with railway transfers. The initial preference for a mode and to avoid railway transfer were also found to vary along the sample, as illustrated by the results of the panel mixed logit model.

Sub-research question 3: To what extent do the key attribute influencing traveller's behaviour on train routes with transfers impact preferences for this mode for leisure long-distance travel?
After highlighting the initial preference for other modes and desire to avoid railway transfer, an analysis of the most impactful elements in travel behaviour in train with transfer routes and the trade-offs made between the different characteristics of the transfer and the trip in its totality was made.
Regarding the attributes related to an entire trip, the overall travel time and travel cost, both including access and egress time and cost, were found to have a significant negative impact on the utility of the modes. This impact was more pronounced for lower-income travellers and travellers with prior railway transfer experience. Specifically, lower-income travellers and people with prior experience with railway transfer were found to be more sensitive to travel costs, while, people with lower-income travellers were found to be less sensitive to travel time.
Concerning attributes specifically related to railway transfers, transfer time and transfer type are considered the the most important elements for the respondents, followed by the delay of the first train. In contrast, the frequency of the second train was not found to significantly improve travellers' trade-offs. Furthermore, no interaction between these different attributes was identified in the analysis. The influence of transfer time on travellers' preferences was found to be non-linear. Travellers exhibited a preference for longer transfer times up to a certain point, beyond which this increase in preference became lower before declining when the transfer time increased further. Gender differences were observed in transfer time preferences, with women showing a preference for shorter travel times than men. An increase in the delay of the first train negatively impacted the utility of railway travel with transfers, although this impact was less significant than that of an increase in transfer time. This is illustrated by the comparison between their travel time penalty. One additional minute of transfer time is associated with a penalty of 1,48 minutes, while an additional minute of delay of the first train is associated with a penalty of 0,49 minute. Regarding transfer type, while lifts and stairs were not found to be highly significant, in the analysis, only escalator was considered as representing the cross-station transfer option, showing a strong dispreference for cross-station transfer in comparison to cross-platform transfer. This is quantified by the penalty associated with changing platforms, which is perceived as equivalent to 20 additional minutes of transfer time. Furthermore, travellers are willing to pay approximately 16€ more to have a transfer on the same platform. With the panel mixed logit model, it was found that the

different transfer-related attributes do not impact all travellers in the same way.

Having answered all the sub-research questions allows to answer the main research question.

Findings revealed strong initial preferences for car, plane, and direct train over train with transfers, with travellers willing to pay 50€, 48€ and 32€ to avoid a train transfer if car, direct train or plane are respectively available. All attributes except transfer time negatively impacted utility, with transfer time increasing utility up to a certain threshold, beyond which it was considered too long. Travel time, travel cost, transfer time, delay of the first train, and cross-station transfers were identified as the most influential factors in travellers' decisions, while a reduction in the frequency of the second train did not significantly affect choices. Furthermore, an additional minute of transfer time and delay of the first train are more penalized than an extra minute of total travel time, valued as 1,48 minute for transfer time and 0,49 minute for delay.

8.2. Discussion and recommendations

In this last chapter, the research and its results are discussed in Section 8.2.1 and recommendations, both societal and in term of further research are drawn in Section 8.2.2.

8.2.1. Discussion

Comparison to similar studies

The significant parameters considered during transfer where found to align with previous studies on different distances and modes. However, a difference was observable with the frequency of the second train attribute. In this study, this attribute was not considered as highly significant by the travellers in their choices. In a couple of study in regional railway in the Netherlands, a decrease of the frequency of the connective train was considered as strongly impacting the utility of the mode (Bovy & Hoogendoorn-Lanser, 2005; de Keizer et al., 2015).
Transfer time was also found to have a penalty and to be perceived as longer than travel time, but with a higher penalty than in Arentze and Molin, 2013 and de Keizer et al., 2015. In these studies on regional railway travel in the Netherlands, the penalty for a 10-minute transfer time was found to be equivalent to 12 minutes (Arentze & Molin, 2013) and the penalty of 1 additional minute of transfer time was found to be 1,67 minute (de Keizer et al., 2015). In this study, the penalty of a 10 minutes of transfer time is equivalent to 15 of travel time and an additional minute of transfer time is perceived as 2,48 minutes of extra travel time.
In this study, cross-station transfers were found to bring disutility to the rail with transfer alternative, which is similar to findings from Douglas and Jones.
To finish, the WTPs to avoid a railway transfer if other direct options are available were found to belong to a similar range than the WTP to avoid plane connection, ranging from 32€ to 50€ in this study, and from 20$ to 82€ in diverse studies on plane transfers dispreferences.

Limitations

The study has several limitations linked to its generalisability and transferability because of the specific context assumption and sample bias, as well as limitations linked to the methodological choices and assumptions made in the choice experiment construction.

Context

A specific context was assumed for the choice experiment, focusing on leisure trips between two European cities distant of approximately 500 kilometres. It was further assumed that the respondent was travelling with one companion, and carrying a single piece of hand-luggage. The results of the study are only applicable within this specific context and cannot be generalized to different scopes and contexts. Firstly, the results may vary significantly with different trip distances. For longer distances than the 500 kilometers considered in the survey, preferences for travelling by plane might be more pronounced. For shorter distances, preferences for travelling by train could possibly be higher. However, the disutility associated with transfers could change, as shorter overall travel times might lead to shorter train legs, reducing the opportunity to engage in activities during the trip. Secondly, the leisure trip purpose may yield different results compared to other trip purposes, such as business trip. Business travellers could be more sensitive to missed connections and associated travel time increase, given their need to meet work obligations at their destination. Additionally, travelling with one person could lead to different results compared to travelling alone or with a larger group, which could influence stress levels in relation to a railway transfer, leading to different preferences for the transfer-related characteristics. Similarly, the type of luggage could also play a role in preferences. Travelling without luggage could reduce the penalty associated with changing platforms while carrying more luggage might decrease the initial preference for plane travel due to the additional costs and time required for baggage check-in. The real impact of these contextual elements can only be confirmed through comparative studies conducted in different contexts.

Sample bias

Limitations related to sample bias were found. The sample was compared to the Dutch population, as the survey was predominantly distributed in the Netherlands. It was found that the sample significantly differs from the Dutch population, except in terms of gender. There is an overrepresentation of young respondents, students, working full-time and respondents with a higher level of education. The preferences identified in the survey reflect the characteristics of this specific sample. A sample with different socio-demographic attributes might yield different results, limiting the generalisability of the study to the broader Dutch population. Moreover, the fact that the majority of the sample had prior experience with railway transfer can also lead to different results than a sample that would include a majority of participants with no experience with railway transfers. Additionally, since the survey was mostly distributed in the Netherlands, the results are likely influenced by respondents' experiences with the Dutch railway system, known for its efficiency and quality. Respondents from countries with less developed railway systems might exhibit stronger dispreferences for train travel, particularly involving transfers. Consequently, the policy and operator recommendations derived from this study might not be applicable in regions with different railway infrastructures.

Methodology

Various assumptions were made in the construction of the choice experiment and introduced further limitations to the study.

In the choice experiment, six attributes were used for the train with transfer alternatives, four of them being specifically related to transfer characteristics. While all of them were deemed important to accurately describe the transfer and to avoid respondents to do assumptions about the transfer that will be not known by the researcher, their number might have overwhelmed respondents, leading them to disregard some attributes and focus only on others. It was assumed that rail alternatives including more than one transfer would always be excluded by respondents in their choices for simplification, but potential further trade-offs could have been observed if additional transfers had been included. Furthermore, transfer time is actually included in the overall travel time, which could lead to an overestimation of the parameters, as is it accounted twice.

Regarding the unreliability of the first train attribute, its construction and representation could have been different, potentially leading to different interpretations and results. Their values could lack realism as they were based on lognormal distributions derived from percentages of reliability, using the the on-time definition of less than five minutes delay, as no railway reliability data specific to long-distance lines were available. The definition of being on-time varies per country, bus also from train type, as the threshold is larger for regional and international trains in Europe, ranging from 15 to 20 minutes. Here, the definition for intercity and sprinters in the Netherlands was used, which led to different distributions and then different results regarding the unreliability of the first train. The representation of this unreliability with five different delay times that could happen for the found different levels could have been considered as too complicated to understand for the respondents and then not considered by them. This complexity could have made it difficult to consider trade-offs between delay and transfer time, which was not significant in the study as no significant interaction between these two attributes was found.

Furthermore, different choices of attributes in the choice experiment could lead to different results. In this study, the focus is made on operability-related attributes, but other factors such as ticket booking processes, transfer station characteristics, and the availability of transfer information before and during

the transfer could also be significant in travellers' choices.
For constructing of the choice set, 16 choices were considered, divided into two blocks. During analysis with the MNL model, some combinations of attributes and interactions led to convergence issues, preventing further testing of more complex attribute combinations. This might be linked to an insufficient number of choices, providing less freedom in data analysis with the MNL model.
The use of stated preferences also introduced limitations in terms of what the travellers will actually choose in real-life, as it reflects theoretical choices based on hypothetical characteristics of the alternatives. It does not guarantee that the participants will actually choose this option in real life. Despite mentioning the environment in relation to the study after the choices and the non-specific mention of the study being focused on railway transfers and the larger use of railway, respondents could have chosen more environmental options they will not choose in reality, to adapt their answer to what they think will be expected or socially acceptable to choose.
Finally, the survey duration, influenced by the number of questions and the explanation of the different attributes, led to more than one quarter of the original number of respondents to not complete the survey. A simpler survey with a smaller choice set and fewer questions could have resulted in a higher completion rate and a larger data set.

8.2.2. Recommendations

Practice recommendations

Based on the findings of the study, several practice recommendations are proposed to enhance the railway transfer experience and encourage a shift towards rail travel.

Since transfer time was identified as a significant factor in railway transfer, operators should prioritize optimizing transfer times when designing timetables.
The delay of the first train contributes significantly to the disutility of railway transfers, probably due to the fear of missed connections. In the EU,country level, governments already impose fines on operators if service quality objectives, such as reliability performance are not met. But the indicators and their benchmarks are currently varied across countries. For international travel, this can result in inconsistent performance within a single trip. Standardizing performance objectives across the EU, with uniform benchmarks for all railway operators, would be beneficial, for example by including a common definition of reliability. These performance objectives could be further extended to more various objectives such as the quality and quantity of information provided and the quality and services of the stations, which could be used at intensive for operators to provide clearer information and improve their facilities. This last point could be applied to infrastructure managers, in the case where the operators are not in charge of the station infrastructures. Furthermore, the EU could oblige railway operators to provide clear information on the reliability of trains at the time of booking. This transparency could pressure operators to improve their reliability. The operators should, when possible, apply more coordination between connecting trains, with second train waiting transfer passengers if first train is late. If impossible, operators should rebook passengers to the next train or help in rebooking if a different operator is involved in the second leg, with more coordination between the different railway operators. Similar to air travel, compensation should be provided if the last train of the day is missed due to a transfer, including assisted rebooking for the next morning's train and, if necessary, overnight accommodation.

For particularly busy transfers, cross-platform transfers should be favoured. If cross-station transfers are necessary, installation of lifts at all platforms should be assured. Information about transfers should be communicated on the train, not only the platform number but also detailed instructions on how to navigate the transfer, including whether lifts are available, average walking times, and current transfer times. This information should also be available in the operator app, with navigation support in different languages.

Policies aiming at reducing the environmental impact of travel should be introduced, such as carbon pricing mechanisms to penalise higher-emission alternatives, stimulating a modal shift to rail travel as seen in scenarios 2 and 3 in the model application. This could include mandatory emission compensation fees for airlines passengers. Railway operators could introduce price incentives related to transfers, offering more flexible fares with reductions proportional to the number of transfers, or providing offers on food and services during journeys that include transfers.

Future research recommendations

Based on the results and the limitations of the study, recommendations for further research related to the topic are provided.

To enhance the generalizability of the results, comparative studies using similar attributes and modelling approaches could be conducted in various contexts. This could include different distance ranges, for example between 200 and 400 kilometers or more than 600 kilometers, different trip purposes, such as business travel, different number of travel companions, such as travelling alone or with a larger group, or travelling with a different type of luggage. Further research could also explore the impact of respondents' nationalities on their choices, by conducting similar choice experiments in different European countries with varying levels of railway operational performance and infrastructure quality, and comparing the results across countries.

Additional studies could investigate different attributes related to railway transfers for long-distance travel in Europe, focusing on different aspects of these transfers. For instance, research could examine the impact of the booking process, the impact of the quality of the transfer infrastructures and services, or the impact of the type and timing of information provided to travellers about transfers. Studies could also consider scenarios involving more than one railway transfer in the choice experiment. Furthermore, the effect of monetary incentives for railway transfers could be evaluated by comparing different incentive schemes to a base scenario without any incentives. Finally, different methods and models could be used to study preferences related to railway transfer. For example, using revealed preferences data instead of stated preferences data could provide insights into actual behaviour. Additionally, applying discrete choice models with decision rules other than random maximum utility, such as random regret minimization (RRM), where participants aim to minimize their regret, could offer a different perspective on decision-making processes.

Bibliography

Aamaas, B., Borken-Kleefeld, J., & Peters, G. P. (2013). The climate impact of travel behavior: A German case study with illustrative mitigation options. *Environmental Science & Policy*, *33*, 273–282. https://doi.org/10.1016/j.envsci.2013.06.009

Adler, T., Falzarano, C. S., & Spitz, G. (2005). Modeling Service Trade-Offs in Air Itinerary Choices [Publisher: SAGE Publications Inc]. *Transportation Research Record*, *1915*(1), 20–26. https://doi.org/10.1177/0361198105191500103

Agency, E. E. (2024). *Greenhouse gas emissions from transport*. https://www.eea.europa.eu/en/analysis/indicators/greenhouse-gas-emissions-from-transport?activeAccordion=

Alonso-González, M. J., van Oort, N., Cats, O., Hoogendoorn-Lanser, S., & Hoogendoorn, S. (2020). Value of time and reliability for urban pooled on-demand services. *Transportation Research Part C: Emerging Technologies*, *115*, 102621. https://doi.org/10.1016/j.trc.2020.102621

Álvarez, A. G. (2010). Energy Consumption and Emissions of High-Speed Trains [Publisher: SAGE Publications Inc]. *Transportation Research Record*, *2159*(1), 27–35. https://doi.org/10.3141/2159-04

Aparicio, A. (2016). Exploring Recent Long-distance Passenger Travel Trends in Europe. *Transportation Research Procedia*, *14*, 3199–3208. https://doi.org/10.1016/j.trpro.2016.05.262

Arentze, T. A., & Molin, E. J. E. (2013). Travelers' preferences in multimodal networks: Design and results of a comprehensive series of choice experiments. *Transportation Research Part A: Policy and Practice*, *58*, 15–28. https://doi.org/10.1016/j.tra.2013.10.005

Avogadro, N., Cattaneo, M., Paleari, S., & Redondi, R. (2021). Replacing short-medium haul intra-European flights with high-speed rail: Impact on CO2 emissions and regional accessibility. *Transport Policy*, *114*, 25–39. https://doi.org/10.1016/j.tranpol.2021.08.014

Baumeister, S. (2019). Replacing short-haul flights with land-based transportation modes to reduce greenhouse gas emissions: The case of Finland. *Journal of Cleaner Production*, *225*, 262–269. https://doi.org/10.1016/j.jclepro.2019.03.329

Behrens, C., & Pels, E. (2012). Intermodal competition in the London–Paris passenger market: High-Speed Rail and air transport. *Journal of Urban Economics*, *71*(3), 278–288. https://doi.org/10.1016/j.jue.2011.12.005

Bergantino, A. S., & Madio, L. (2020). Intermodal competition and substitution. HSR versus air transport: Understanding the socio-economic determinants of modal choice. *Research in Transportation Economics*, *79*, 100823. https://doi.org/10.1016/j.retrec.2020.100823

Bierlaire, M. (2003). BIOGEME: A free package for the estimation of discrete choice models. *Proceedings of the 12th Swiss Transport Research Conference (STRC)*.

Borken-Kleefeld, J., Fuglestvedt, J., & Berntsen, T. (2013). Mode, Load, And Specific Climate Impact from Passenger Trips. *Environmental Science & Technology*, *47*(14), 7608–7614. https://doi.org/10.1021/es4003718

Bovy, P. H. L., & Hoogendoorn-Lanser, S. (2005). Modelling route choice behaviour in multi-modal transport networks. *Transportation*, *32*(4), 341–368. https://doi.org/10.1007/s11116-004-7963-2

Cantos-Sánchez, P., Moner-Colonques, R., Ruiz-Buforn, A., & Sempere-Monerris, J. J. (2023). Welfare and environmental effects of short-haul flights bans. *Transport Economics and Management*, *1*, 126–138. https://doi.org/10.1016/j.team.2023.08.002

Cascajo, R., Suárez, E., Herrero, F., & Monzón, A. (2019). User perception of transfers in multimodal urban trips: A qualitative study. *International Journal of Sustainable Transportation*, *13*, 393–406. https://doi.org/10.1080/15568318.2018.1476632

Caulfield, J. (2019). *Thematic analysis: Explanation and key steps*. https://www.scribbr.com/methodology/thematic-analysis/

Ceder, A., Chowdhury, S., Taghipouran, N., & Olsen, J. (2013). Modelling public-transport users' behaviour at connection point. *Transport Policy*, *27*, 112–122. https://doi.org/10.1016/j.tranpol.2013.01.002

Choi, J. H., Wang, K., Xia, W., & Zhang, A. (2019). Determining factors of air passengers' transfer airport choice in the Southeast Asia – North America market: Managerial and policy implications. *Transportation Research Part A: Policy and Practice*, *124*, 203–216. https://doi.org/10.1016/j.tra.2019.03.008

Chowdhury, S., Ceder, A. (, & Schwalger, B. (2015). The effects of travel time and cost savings on commuters' decision to travel on public transport routes involving transfers. *Journal of Transport Geography*, *43*, 151–159. https://doi.org/10.1016/j.jtrangeo.2015.01.009

Christensen, L. (2016). Environmental Impact of Long Distance Travel. *Transportation Research Procedia*, *14*, 850–859. https://doi.org/10.1016/j.trpro.2016.05.033

Coldren, G. M., Koppelman, F. S., Kasturirangan, K., & Mukherjee, A. (2003). Modeling aggregate air-travel itinerary shares: Logit model development at a major US airline. *Journal of Air Transport Management*, *9*(6), 361–369. https://doi.org/10.1016/S0969-6997(03)00042-5

Commission, E. (2019). Delivering the european green deal. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_en#making-transport-sustainable-for-all

Commission, E. (2020). Sustainable and smart mobility strategy. https://transport.ec.europa.eu/transport-themes/mobility-strategy_en

Commission, E. (2021a). Action plan to boost passenger rail. https://transport.ec.europa.eu/news-events/news/action-plan-boost-passenger-rail-2021-12-14_en

Commission, E. (2021b). Efficient and green mobility. https://transport.ec.europa.eu/news-events/news/efficient-and-green-mobility-2021-12-14_en

Dalkic, G., Balaban, O., Tuydes-Yaman, H., & Celikkol-Kocak, T. (2017). An assessment of the CO2 emissions reduction in high speed rail lines: Two case studies from Turkey. *Journal of Cleaner Production*, *165*, 746–761. https://doi.org/10.1016/j.jclepro.2017.07.045

de Barros, A. G., Somasundaraswaran, A. K., & Wirasinghe, S. C. (2007). Evaluation of level of service for transfer passengers at airports. *Journal of Air Transport Management*, *13*(5), 293–298. https://doi.org/10.1016/j.jairtraman.2007.04.004

de Keizer, B., Kouwenhoven, M., & Hofker, F. (2015). New Insights in Resistance to Interchange. *Transportation Research Procedia*, *8*, 72–79. https://doi.org/10.1016/j.trpro.2015.06.043

Dobruszkes, F., Mattioli, G., & Mathieu, L. (2022). Banning super short-haul flights: Environmental evidence or political turbulence? *Journal of Transport Geography*, *104*, 103457. https://doi.org/10.1016/j.jtrangeo.2022.103457

Donners, B. (2016). *Erasing borders, european rail passenger potential* [Master's thesis]. Delft University of Technology.

Douglas, N., & Jones, M. (2013). Estimating transfer penalties and standardised income values of time by stated preference survey. *Australasian Transport Research Forum, ATRF 2013 - Proceedings*.

Espino, R. (2019). Análisis de la disposición a pagar por no trasbordar de los usuarios de transporte público [Number: 2]. *Studies of Applied Economics*, *37*(2), 230–246. https://doi.org/10.25115/eea.v37i2.2610

Euronews. (2023). *Short-haul ban: These european countries could soon see the end of domestic flights*. https://www.euronews.com/green/2023/06/01/short-haul-ban-these-european-countries-could-soon-see-the-end-of-domestic-flights

Eurostat. (2024). *Modal split of passenger transport*. https://ec.europa.eu/eurostat/databrowser/view/tran_hv_ms_psmod/default/table?lang=en

González-Savignat, M. (2004). Competition in Air Transport: The Case of the High Speed Train [Publisher: [London School of Economics, University of Bath, London School of Economics and University of Bath, London School of Economics and Political Science]]. *Journal of Transport Economics and Policy*, *38*(1), 77–107. Retrieved April 28, 2023, from https://www.jstor.org/stable/20173046

Guis, N., & Nijënstein, S. (2015). Modelleren van klantvoorkeuren in dienstregelingsstudies.

Guo, Z., & Wilson, N. H. M. (2004). Assessment of the Transfer Penalty for Transit Trips Geographic Information System-Based Disaggregate Modeling Approach [Publisher: SAGE Publications Inc]. *Transportation Research Record*, *1872*(1), 10–18. https://doi.org/10.3141/1872-02

Guo, Z., & Wilson, N. H. M. (2011). Assessing the cost of transfer inconvenience in public transport systems: A case study of the London Underground. *Transportation Research Part A: Policy and Practice*, *45*(2), 91–104. https://doi.org/10.1016/j.tra.2010.11.002

Ha, J., Lee, S., & Ko, J. (2020). Unraveling the impact of travel time, cost, and transit burdens on commute mode choice for different income and age groups. *Transportation Research Part A: Policy and Practice*, *141*, 147–166. https://doi.org/10.1016/j.tra.2020.07.020

Herring, J., Lurkin, D. V., Garrow, D. L. A., John-Paul Clarke, D., & Bierlaire, D. M. (2019). Airline customers' connection time preferences in domestic U.S. markets. *Journal of Air Transport Management*, *79*, 101688. https://doi.org/10.1016/j.jairtraman.2019.101688

Hess, S. (2008). Treatment of reference alternatives in stated choice surveys for air travel choice behaviour. *Journal of Air Transport Management*, *14*(5), 275–279. https://doi.org/10.1016/j.jairtraman.2008.06.001

Hess, S., Adler, T., & Polak, J. W. (2007). Modelling airport and airline choice behaviour with the use of stated preference survey data. *Transportation Research Part E: Logistics and Transportation Review*, *43*(3), 221–233. https://doi.org/10.1016/j.tre.2006.10.002

Heufke Kantelaar, M., Molin, E., Cats, O., Donners, B., & Wee, B. v. (2022). Willingness to use night trains for long-distance travel. *Travel Behaviour and Society*, *29*, 339–349. https://doi.org/10.1016/j.tbs.2022.08.002

Johnson, D., Hess, S., & Matthews, B. (2014). Understanding air travellers' trade-offs between connecting flights and surface access characteristics. *Journal of Air Transport Management*, *34*, 70–77. https://doi.org/10.1016/j.jairtraman.2013.08.001

Kamga, C., & Yazici, M. A. (2014). Achieving environmental sustainability beyond technological improvements: Potential role of high-speed rail in the United States of America. *Transportation Research Part D: Transport and Environment*, *31*, 148–164. https://doi.org/10.1016/j.trd.2014.06.011

Lakatos, A., & Mándoki, P. (2020). Mode-choice Analysis in Long-distance, Parallel Public Transport. *Transportation Research Procedia*, *44*, 332–341. https://doi.org/10.1016/j.trpro.2020.02.034

Landau, S., Gosling, G. D., Small, K., & Adler, T. (2016). Measuring Air Carrier Passengers' Values of Time by Trip Component [Publisher: SAGE Publications Inc]. *Transportation Research Record*, *2569*(1), 24–31. https://doi.org/10.3141/2569-03

Lu, J., Meng, Y., Timmermans, H., & Zhang, A. (2021). Modeling hesitancy in airport choice: A comparison of discrete choice and machine learning methods. *Transportation Research Part A: Policy and Practice*, *147*, 230–250. https://doi.org/10.1016/j.tra.2021.03.006

Mabit, S. L., Rich, J., Burge, P., & Potoglou, D. (2013). Valuation of travel time for international long-distance travel – results from the Fehmarn Belt stated choice experiment. *Journal of Transport Geography*, *33*, 153–161. https://doi.org/10.1016/j.jtrangeo.2013.10.003

Malichová, E., Cornet, Y., & Hudák, M. (2022). Travellers' use and perception of travel time in long-distance trips in Europe. *Travel Behaviour and Society*, *27*, 95–106. https://doi.org/10.1016/j.tbs.2021.12.003

Martín, J. C., & Nombela, G. (2007). Microeconomic impacts of investments in high speed trains in Spain. *The Annals of Regional Science*, *41*(3), 715–733. https://doi.org/10.1007/s00168-007-0116-8

Ministry of the Energy Transition. (2023). European overview of ghg emissions.

Morlotti, C., Birolini, S., Malighetti, P., & Redondi, R. (2023). A latent class approach to estimate air travelers' propensity toward connecting itineraries. *Research in Transportation Economics*, *99*, 101283. https://doi.org/10.1016/j.retrec.2023.101283

Ortúzar, J. d. D., & Simonetti, C. (2008). Modelling the demand for medium distance air travel with the mixed data estimation method. *Journal of Air Transport Management*, *14*(6), 297–303. https://doi.org/10.1016/j.jairtraman.2008.08.002

Park, Y., & Ha, H.-K. (2006). Analysis of the impact of high-speed railroad service on air transport demand. *Transportation Research Part E: Logistics and Transportation Review*, *42*(2), 95–104. https://doi.org/10.1016/j.tre.2005.09.003

Román, C., Espino, R., & Martín, J. C. (2007). Competition of high-speed train with air transport: The case of Madrid–Barcelona. *Journal of Air Transport Management*, *13*(5), 277–284. https://doi.org/10.1016/j.jairtraman.2007.04.009

Statista. (2021). *Punctuality of regional passenger rail services in europe by country*. https://www.statista.com/statistics/1255048/punctuality-regional-passenger-rail-services-europe-by-country/

Swierstra, A. B., van Nes, R., & Molin, E. J. (2017). Modelling travel time reliability in public transport route choice behaviour. *European Journal of Transport and Infrastructure Research*, *17*(2). https://doi.org/10.18757/ejtir.2017.17.2.3194

Theis, G., Adler, T., Clarke, J.-P., & Ben-Akiva, M. (2006). Risk Aversion to Short Connections in Airline Itinerary Choice [Publisher: SAGE Publications Inc]. *Transportation Research Record*, *1951*(1), 28–36. https://doi.org/10.1177/0361198106195100104

Tseng, Y.-Y., Verhoef, E., de Jong, G., Kouwenhoven, M., & van der Hoorn, T. (2009). A pilot study into the perception of unreliability of travel times using in-depth interviews. *Journal of Choice Modelling*, *2*(1), 8–28. https://doi.org/10.1016/S1755-5345(13)70002-2

van Hagen, M., de Vos, P. H., Andringa, T., & Pieren, R. (2019). A soundscape approach to assess and predict passenger satisfaction. *Proceedings of the 13th International Workshop on Railway Noise (IWRN13)*.

Warburg, V. (2006). Modeling demographic and unobserved heterogeneity in air passengers' sensitivity to service attributes in itinerary choice.

Wardman, M. (2001). A review of British evidence on time and service quality valuations. *Transportation Research Part E: Logistics and Transportation Review*, *37*(2), 107–128.

Witlox, F., Zwanikken, T., Jehee, L., Donners, B., & Veeneman, W. (2022). Changing tracks: Identifying and tackling bottlenecks in European rail passenger transport. *European Transport Research Review*, *14*(1), 7. https://doi.org/10.1186/s12544-022-00530-9

A

Interviews script

Travel frequency and mode use

1. How frequently are you travelling internationally? Rarely, once a year, few times a year, once a month, once week…

2. Which mode(s) are you using to do so?

Comfort grading

3. Grading on comfort when taking train (direct) (How comfortable are you to travel by train for international travel?)? Grading if transfer involved (1 to 5)

4. Grading on comfort when taking plane (direct)? Grading if transfer involved (1 to 5)

If had previous experience with international train trips

Previous transfer experience

5. In previous international travels with trains, did you already have transfer(s) along the way or only used direct trains?
If took train for international travel and had a transfer

6. What was your worst experience with railway transfer?

7. What was your best experience with railway transfer?

Important elements in railway transfers

8. What are the elements that for you impact the most your experience with railway transfers, or that could impact it the most, what do you prefer and dislike the most in railway transfer? (Examples: small/high transfer time, walking distance, if next train on same or next platform, change of train station…)

Additional questions
Is your mode choice or choice of route (direct or with transfers) impacted by your trip purpose (travelling for work/holidays)? Or if you are traveling alone or in group? Inbound or outbound trips?

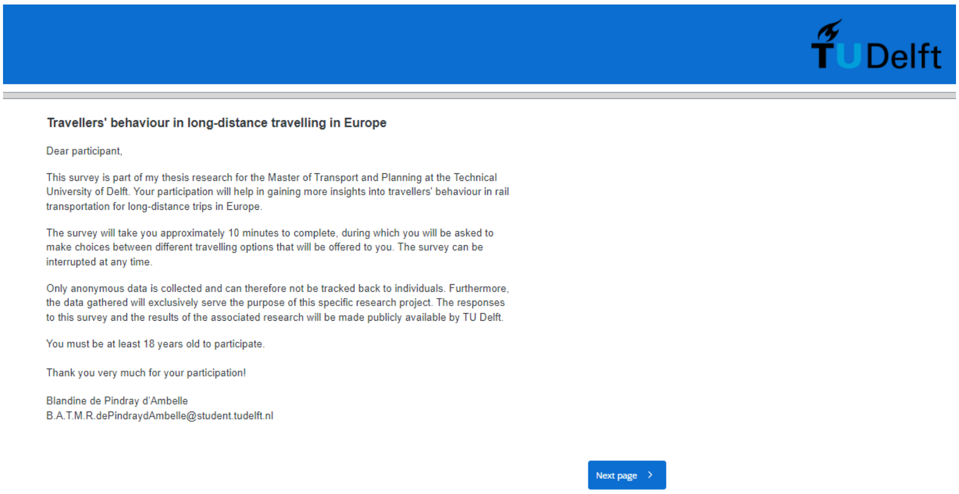
B

Ngene syntax

```
? Survey syntax
design
;alts = traint1, traint2
;rows = 16
;orth = seq
;block = 2
;model :
U(traint1) = Btttraint * TTtrain[3,4.5,6,7.5] + Btctraintt * TCtrain[30,60,90,120] + Btransfert * TransferT[10,20,30,40] + Brel * Rel[0,1,2,3] + Bf * F[0,1] + Btransfertype * Transfertype[0,1,2,3] + Binteraction * TransferT * Rel /
U(traint2) = Btttraint * TTtrain + Btctraintt * TCtrain + Btransfert * TransferT + Brel * Rel + Bf * F + Btransfertype * Transfertype + Binteraction * TransferT * Rel $
```

C

Survey



TU Delft

Travellers' behaviour in long-distance travelling in Europe

Dear participant,

This survey is part of my thesis research for the Master of Transport and Planning at the Technical University of Delft. Your participation will help in gaining more insights into travellers' behaviour in rail transportation for long-distance trips in Europe.

The survey will take you approximately 10 minutes to complete, during which you will be asked to make choices between different travelling options that will be offered to you. The survey can be interrupted at any time.

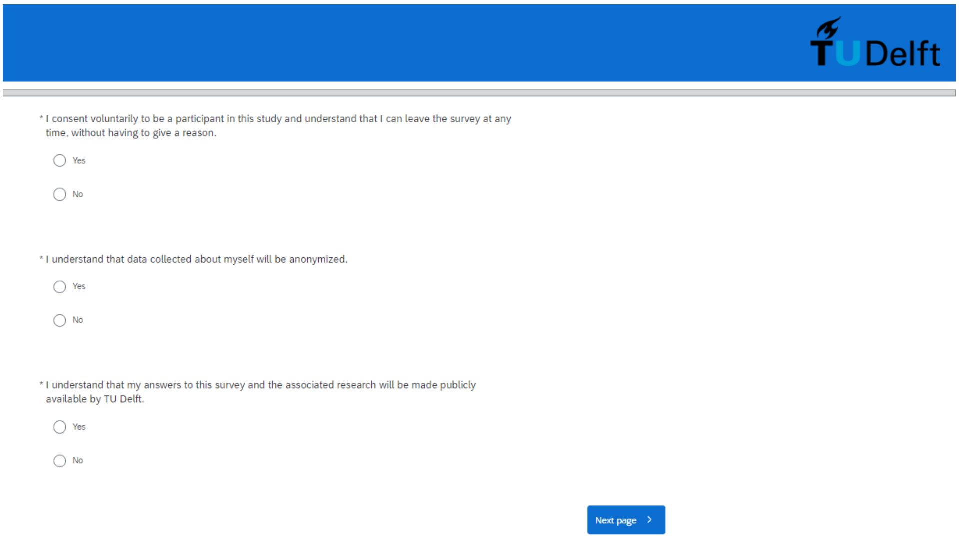
Only anonymous data is collected and can therefore not be tracked back to individuals. Furthermore, the data gathered will exclusively serve the purpose of this specific research project. The responses to this survey and the results of the associated research will be made publicly available by TU Delft.

You must be at least 18 years old to participate.

Thank you very much for your participation!

Blandine de Pindray d'Ambelle
B.A.T.M.R.dePindraydAmbelle@student.tudelft.nl

Next page >



TU Delft

* I consent voluntarily to be a participant in this study and understand that I can leave the survey at any time, without having to give a reason.

- ○ Yes
- ○ No

* I understand that data collected about myself will be anonymized.

- ○ Yes
- ○ No

* I understand that my answers to this survey and the associated research will be made publicly available by TU Delft.

- ○ Yes
- ○ No

Next page >

The survey will include a total of 20 questions.
To begin, a couple of questions about your travel habits are asked.

* 1. How frequently are you traveling abroad within Europe for leisure, for distances greater than 100 kilometers?

- ◯ Rarely or never
- ◯ Once a year
- ◯ 2-3 times a year
- ◯ 4-5 times a year
- ◯ More than 5 times a year

* 2. What mode of transport do you most frequently use for these types of trips?

- ◯ Plane
- ◯ Train
- ◯ Car
- ◯ Bus
- ◯ Other

In the following part of the survey, you will be asked to make **8 choices** between different modes of transportation. Each of these choices is divided into **two parts**:

- **Part 1**: Choice between **two trains with one transfer**.
- **Part 2**: Choice between the **previously chosen option**, a **direct train**, a **direct plane** and a **car**, as driver or passenger.

The following picture is an example of a choice that will be presented to you.

	Train with transfer (1)	Train with transfer (2)
Door to door travel time	3h30	5h30
Travel cost	90€	120€
Transfer time	40 min	20 min
Delay first train *5 delay times that have the same chance to happen*	0 min 2 min 4 min 7 min 15 min	0 min 0 min 2 min 3 min 5 min
Frequency second train	One every 1h	One every 2h
Transfer type	Cross-platform	Cross-station with escalator

What is included in each characteristic of the transport mode is presented below. Taking a moment to carefully review these characteristics will help you to answer the questions that will follow.

- **Door-to-door travel time**: Time from your starting point to your final destination, including the time to and from the airport or the train station. Additionally:
    - Plane alternative: 1h30 before boarding is included (security check, walking to the gate and waiting at the gate). No luggage check-in.
    - Transfer train alternatives: transfer time included.
    - Car alternative: potential traffic jams and stops to relax included.

- **Travel cost**: All costs are included.
    - Plane alternative: cost to and from the airport included.
    - Planes and trains alternatives: cost for one traveller.
    - Car alternative: cost can be shared with other traveller.

- **Transfer time**: Time between the scheduled arrival time of the first train and the scheduled departure time of the second train.

- **Delay first train**: Potential delay times of the first train before the transfer, that will impact the transfer time. You will be shown 5 delays that are equally likely to happen.

- **Frequency second train**: Illustrates how often a new train is departing for your destination at your transfer station.

- **Transfer type**
    - **Cross-platform**: the second train will depart from the same platform where the first train arrived.
    - **Cross-station with *stairs***: you will need to change platform during transfer by going through a passage or over a bridge, with only stairs available on both platforms.
    - **Cross-station with *lift***: change of platform during transfer, with a lift available on both platforms.
    - **Cross-station with *escalator***: change of platform during transfer, with an escalator available on both platforms.

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When answering the questions, imagine that you are planning to do the following trip:

	Holidays
	~ 500 km Between 2 European cities *(example: Paris to Amsterdam)*
	Travelling with one person
	One piece of hand luggage / person

(Prices per person, except for car)

Next page >

*

	Train with transfer (1)	Train with transfer (2)
Door to door travel time	5h30	5h30
Travel cost	30€	60€
Transfer time	30 min	30 min
Delay first train *5 delay times that have the same chance to happen*	0 min 2 min 6 min 15 min 30 min	0 min 0 min 2 min 3 min 5 min
Frequency second train	One every 1h	One every 1h
Transfer type	Cross-station with escalator	Cross-station with stairs

3A. Given these two train alternatives, which one would you choose for your trip?

- Train with transfer 1
- Train with transfer 2

Next page >

*

	Train with transfer (1)	Direct train	Direct plane	Car
Door to door travel time	5h30	4h30	3h45	6h45
Travel cost	30€	110€	125€	90€
Transfer time	30 min			
Delay first train *5 delay times that have the same chance to happen*	0 min 2 min 6 min 15 min 30 min			
Frequency second train	One every 1h			
Transfer type	Cross-station with escalator			

3B. Given the **previously chosen train alternative and the three other alternatives** shown here, which one would you choose for your trip?

- Train with transfer
- Direct train
- Direct plane
- Car

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*

	Train with transfer (1)	Train with transfer (2)
Door to door travel time	6h30	6h30
Travel cost	90€	120€
Transfer time	30 min	30 min
Delay first train *5 delay times that have the same chance to happen*	0 min 2 min 4 min 7 min 15 min	0 min 1 min 2 min 4 min 8 min
Frequency second train	One every 2h	One every 2h
Transfer type	Cross-station with lift	Cross-platform

4A. Given these two train alternatives, which one would you choose for your trip?

- ◯ Train with transfer 1
- ◯ Train with transfer 2

Next page >

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*

	Train with transfer (1)	Direct train	Direct plane	Car
Door to door travel time	6h30	4h30	3h45	6h45
Travel cost	90€	110€	125€	90€
Transfer time	30 min			
Delay first train *5 delay times that have the same chance to happen*	0 min 2 min 4 min 7 min 15 min			
Frequency second train	One every 2h			
Transfer type	Cross-station with lift			

4B. Given the **previously chosen train alternative and the three other alternatives** shown here, which one would you choose for your trip?

- ◯ Train with transfer
- ◯ Direct train
- ◯ Direct plane
- ◯ Car

*

	Train with transfer (1)	Train with transfer (2)
Door to door travel time	6h30	4h30
Travel cost	120€	60€
Transfer time	30 min	40 min
Delay first train *5 delay times that have the same chance to happen*	0 min 1 min 2 min 4 min 8 min	0 min 2 min 6 min 15 min 30 min
Frequency second train	One every 2h	One every 2h
Transfer type	Cross-platform	Cross-station with stairs

5A. Given these two train alternatives, which one would you choose for your trip?

- ◯ Train with transfer 1
- ◯ Train with transfer 2

Next page >

*

	Train with transfer (1)	Direct train	Direct plane	Car
Door to door travel time	6h30	4h30	3h45	6h45
Travel cost	120€	110€	125€	90€
Transfer time	30 min			
Delay first train *5 delay times that have the same chance to happen*	0 min 1 min 2 min 4 min 8 min			
Frequency second train	One every 2h			
Transfer type	Cross-platform			

5B. Given the **previously chosen train alternative and the three other alternatives** shown here, which one would you choose for your trip?

- ◯ Train with transfer
- ◯ Direct train
- ◯ Direct plane
- ◯ Car

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*

	Train with transfer (1)	Train with transfer (2)
Door to door travel time	3h30	6h30
Travel cost	60€	30€
Transfer time	10 min	20min
Delay first train *5 delay times that have the same chance to happen*	0 min 2 min 6 min 15 min 30 min	0 min 2 min 6 min 15 min 30 min
Frequency second train	One every 2h	One every 1h
Transfer type	Cross-station with lift	Cross-platform

6A. Given these two train alternatives, which one would you choose for your trip?

- ◯ Train with transfer 1
- ◯ Train with transfer 2

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*

	Train with transfer (1)	Direct train	Direct plane	Car
Door to door travel time	3h30	4h30	3h45	6h45
Travel cost	60€	110€	125€	90€
Transfer time	10 min			
Delay first train *5 delay times that have the same chance to happen*	0 min 2 min 6 min 15 min 30 min			
Frequency second train	One every 2h			
Transfer type	Cross-station with lift			

6B. Given the **previously chosen train alternative and the three other alternatives** shown here, which one would you choose for your trip?

- ◯ Train with transfer
- ◯ Direct train
- ◯ Direct plane
- ◯ Car

*

	Train with transfer (1)	Train with transfer (2)
Door to door travel time	4h30	3h30
Travel cost	90€	30€
Transfer time	10 min	10 min
Delay first train *5 delay times that have the same chance to happen*	0 min 1 min 2 min 4 min 8 min	0 min 0 min 2 min 3 min 5 min
Frequency second train	One every 1h	One every 2h
Transfer type	Cross-station with stairs	Cross-platform

7A. Given these two train alternatives, which one would you choose for your trip?

- ◯ Train with transfer 1
- ◯ Train with transfer 2

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*

	Train with transfer (1)	Direct train	Direct plane	Car
Door to door travel time	4h30	4h30	3h45	6h45
Travel cost	90€	110€	125€	90€
Transfer time	10 min			
Delay first train *5 delay times that have the same chance to happen*	0 min 1 min 2 min 4 min 8 min			
Frequency second train	One every 1h			
Transfer type	Cross-station with stairs			

7B. Given the **previously chosen train alternative and the three other alternatives** shown here, which one would you choose for your trip?

- ◯ Train with transfer
- ◯ Direct train
- ◯ Direct plane
- ◯ Car

TU Delft

*

	Train with transfer (1)	Train with transfer (2)
Door to door travel time	4h30	4h30
Travel cost	30€	90€
Transfer time	40 min	10 min
Delay first train *5 delay times that have the same chance to happen*	0 min 0 min 2 min 3 min 5 min	0 min 1 min 2 min 4 min 8 min
Frequency second train	One every 2h	One every 1h
Transfer type	Cross-station with escalator	Cross-station with stairs

8A. Given these two train alternatives, which one would you choose for your trip?

- ◯ Train with transfer 1
- ◯ Train with transfer 2

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TU Delft

*

	Train with transfer (1)	Direct train	Direct plane	Car
Door to door travel time	4h30	4h30	3h45	6h45
Travel cost	30€	110€	125€	90€
Transfer time	40 min			
Delay first train *5 delay times that have the same chance to happen*	0 min 0 min 2 min 3 min 5 min			
Frequency second train	One every 2h			
Transfer type	Cross-station with escalator			

8B. Given the **previously chosen train alternative and the three other alternatives** shown here, which one would you choose for your trip?

- ◯ Train with transfer
- ◯ Direct train
- ◯ Direct plane
- ◯ Car

TU Delft

*

	Train with transfer (1)	Train with transfer (2)
Door to door travel time	5h30	5h30
Travel cost	60€	90€
Transfer time	30 min	20 min
Delay first train *5 delay times that have the same chance to happen*	0 min 0 min 2 min 3 min 5 min	0 min 2 min 4 min 7 min 15 min
Frequency second train	One every 1h	One every 2h
Transfer type	Cross-station with stairs	Cross-station with stairs

9A. Given these two train alternatives, which one would you choose for your trip?

- ◯ Train with transfer 1
- ◯ Train with transfer 2

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*

	Train with transfer (1)	Direct train	Direct plane	Car
Door to door travel time	5h30	4h30	3h45	6h45
Travel cost	60€	110€	125€	90€
Transfer time	30 min			
Delay first train *5 delay times that have the same chance to happen*	0 min 0 min 2 min 3 min 5 min			
Frequency second train	One every 1h			
Transfer type	Cross-station with stairs			

9B. Given the **previously chosen train alternative and the three other alternatives** shown here, which one would you choose for your trip?

- ◯ Train with transfer
- ◯ Direct train
- ◯ Direct plane
- ◯ Car

*

	Train with transfer (1)	Train with transfer (2)
Door to door travel time	4h30	3h30
Travel cost	120€	120€
Transfer time	10 min	40 min
Delay first train *5 delay times that have the same chance to happen*	0 min 2 min 4 min 7 min 15 min	0 min 2 min 4 min 7 min 15 min
Frequency second train	One every 1h	One every 1h
Transfer type	Cross-station with escalator	Cross-platform

10A. Given these two train alternatives, which one would you choose for your trip?

◯ Train with transfer 1

◯ Train with transfer 2

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*

	Train with transfer (1)	Direct train	Direct plane	Car
Door to door travel time	4h30	4h30	3h45	6h45
Travel cost	120€	110€	125€	90€
Transfer time	10 min			
Delay first train *5 delay times that have the same chance to happen*	0 min 2 min 4 min 7 min 15 min			
Frequency second train	One every 1h			
Transfer type	Cross-station with escalator			

10B. Given the **previously chosen train alternative and the three other alternatives** shown here, which one would you choose for your trip?

◯ Train with transfer

◯ Direct train

◯ Direct plane

◯ Car

To conclude, we kindly request your answers to the following 8 questions regarding basic information about you and your travel experience with trains.

* 13. What is your gender?

- Male
- Female
- Non-binary
- Prefer not to say

14. What is your year of birth? *(XXXX format)*

* 15. What is your highest completed level of education?

- No formal education
- Primary education
- High school degree or equivalent
- Bachelor's degree
- Master's degree
- Postgraduate education

* 16. What is your household's yearly gross income range?

- Less than 10.000€
- 10.000€ to 20.000€
- 20.000€ to 30.000€
- 30.000€ to 40.000€
- 40.000€ to 50.000€
- 50.000€ to 75.000€
- 75.000€ to 100.000€
- 100.000 to 200.000€
- More than 200.000€

* 17. What is your work status?

- Employed full-time
- Employed part-time
- Unemployed
- Retired
- Student
- Other (Please specify)

* 18. Do you have a driving license?

- Yes
- No

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* 19. Do you have access to a car?

- Yes, I have my own car
- I am sharing a car with other people in my household
- I have access to a car through people outside my household or a shared car
- No, I do not have access to a car

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* 20. Did you have previous experience with railway transfer(s) during a long-distance international trip (distance above 100 km)?

- Yes
- No

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20B. Did you previously experience one of the following during a railway transfer? (Several options can be selected)

- [ ] Missed connection
- [ ] Too long waiting time
- [ ] Difficulties to find the platform
- [ ] Safety issues
- [ ] Lack of amenities in the station
- [ ] Exposed to bad weather in the station
- [ ] Other (Please specify)

20C. You can write here more information about your experience(s) with railway transfer(s)

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If you would like to provide any additional information or comments about the survey, please feel free to use the space provided below.

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D

Base Multinomial Logit Model

D.1. Base model code

```
#Import Biogeme and packages
import pandas as pd
import biogeme as biogeme
import biogeme.database as db
import biogeme.biogeme as bio
from biogeme import models
from biogeme.expressions import Beta, Variable
import os

#Read data
df = pd.read_excel(MNLmodel_UnA.xlsx')

#Define database
database = db.Database("Base_MNLmodel_UnA", df)

#Define variables names as python variables
globals().update(database.variables)

#Define Beta parameters to be estimated
ASC_directtrain = Beta('ASC_directtrain',0,None,None,0)
ASC_plane = Beta('ASC_plane',0,None,None,0)
ASC_car = Beta('ASC_car',0,None,None,0)
B_tt = Beta('B_tt',0,None,None,0)
B_tc = Beta('B_tc',0,None,None,0)
B_transfertime_transfer = Beta('B_transfertime',0,None,None,0)
B_delay_transfer = Beta('B_delay_transfer',0,None,None,0)
#B_Lift_transfer = Beta('B_Lift_transfer',0,None,None,0)
B_Escalator_transfer = Beta('B_Escalator_transfer',0,None,None,0)
B_Stairs_transfer = Beta('B_Stairs_transfer',0,None,None,0)
B_frequency_transfer = Beta('B_frequency_transfer',0,None,None,0)

# Interactions parameters
#B_interaction_Delay_frequency_Transfer = Beta('B_interaction_Delay_frequency_Transfer', 0, None,
None, 0)
#B_interaction_Delay_Transfertime_Transfer = Beta('B_interaction_Delay_Transfertime_Transfer', 0,
None, None, 0)
#B_interaction_Frequency_Transfertime_Transfer = Beta('B_interaction_Frequency_Transfertime_Transfer',
0, None, None, 0)
```

```
#B_interaction_Lift_Transfertime_Transfer = Beta('B_interaction_Lift_Transfertime_Transfer', 0, None,
None, 0)
#B_interaction_Escalator_Transfertime_Transfer = Beta('B_interaction_Escalator_Transfertime_Transfer',
0, None, None, 0)
#B_interaction_Stairs_Transfertime_Transfer = Beta('B_interaction_Stairs_Transfertime_Transfer', 0,
None, None, 0)

# Interactions terms
#Interaction_Delay_frequency_Transfer1 = delay_transfer1 * Dummy_frequency_transfer1
#Interaction_Delay_frequency_Transfer2 = delay_transfer2 * Dummy_frequency_transfer2

#Interaction_Frequency_Transfertime_Transfer1 = Dummy_frequency_transfer1 * transfertime_transfer1
#Interaction_Frequency_Transfertime_Transfer2 = Dummy_frequency_transfer2 * transfertime_transfer2

#Interaction_Delay_Transfertime_Transfer1 = Dummy_Delay_Transfer1 * transfertime_transfer1
#Interaction_Delay_Transfertime_Transfer2 = Dummy_Delay_Transfer2 * transfertime_transfer2

#Interaction_Lift_Transfertime_Transfer1 = Lift_Transfer1 * transfertime_transfer1
#Interaction_Lift_Transfertime_Transfer2 = Lift_Transfer2 * transfertime_transfer2

#Interaction_Escalator_Transfertime_Transfer1 = Escalator_Transfer1 * transfertime_transfer1
#Interaction_Escalator_Transfertime_Transfer2 = Escalator_Transfer2 * transfertime_transfer2

#Interaction_Stairs_Transfertime_Transfer1 = Stairs_Transfer1 * transfertime_transfer1
#Interaction_Stairs_Transfertime_Transfer2 = Stairs_Transfer2 * transfertime_transfer2

# Non-linearity parameters
B_transfertime_transfer_sq = Beta('B_transfertime_sq', 0, None, None, 0)
B_transfertime_transfer_cu = Beta('B_transfertime_cu', 0, None, None, 0)

# Transfer time square and cube terms
transfertime_transfer1_sq = transfertime_transfer1 ** 2
transfertime_transfer1_cu = transfertime_transfer1 ** 3
transfertime_transfer2_sq = transfertime_transfer2 ** 2
transfertime_transfer2_cu = transfertime_transfer2 ** 3

#Utilities
V1 =( B_tt * tt_transfer1 + B_tc * tc_transfer1 + B_transfertime_transfer * transfertime_transfer1 +
B_transfertime_transfer_sq * transfertime_transfer1_sq + B_transfertime_transfer_cu * transfertime_transfer1_cu
+ B_delay_transfer * delay_transfer1 + #B_Lift_transfer * Lift_transfer1 + B_Escalator_transfer * Esca-
lator_transfer1 + B_Stairs_transfer * Stairs_transfer1 + B_frequency_transfer * Dummy_frequency_transfer1
)

V2 =( B_tt * tt_transfer2 + B_tc * tc_transfer2 + B_transfertime_transfer * transfertime_transfer2 +
B_transfertime_transfer_sq * transfertime_transfer1_sq + B_transfertime_transfer_cu * transfertime_transfer1_cu
+ B_delay_transfer * delay_transfer2 + #B_Lift_transfer * Lift_transfer2 + B_Escalator_transfer * Esca-
lator_transfer2 + B_Stairs_transfer * Stairs_transfer2 + B_frequency_transfer * Dummy_frequency_transfer2
)

V3 =( ASC_directtrain + B_tt * tt_train + B_tc * tc_train )

V4 =( ASC_plane + B_tt * tt_plane + B_tc * tc_plane )

V5 =( ASC_car + B_tt * tt_car + B_tc * tc_car )

#Associate utility functions with alternatives
```

```
V = 1: V1,2 :V2,3 :V3,4 :V4,5 :V5
#Associate availabilities with the alternatives
av = 1: av1,2: av2,3: av3,4: av4,5: av5

#Define MNL model
logprob = models.loglogit(V,av,CHOICE)

#Create Biogeme object
the_biogeme = bio.BIOGEME(database,logprob)

#Give name to model
the_biogeme.modelName = 'Base_MNLFinal'

#Estimate model
the_biogeme . calculateNullLoglikelihood (av)
results = the_biogeme.estimate()

#Iterations
biogeme.saveIterations = True

#Get results in Panda table
PResults = results.getEstimatedParameters()
print(PResults)
print(results)
```

D.2. Results

Table D.1: Parameter estimates of generic MNL model

	Value	Rob. Std err	Rob. t-test	Rob. p-value
ASC_car	1,849911822	0,297627193	6,215533611	5,11505E-10
ASC_directtrain	2,481828714	0,284440861	8,725289006	0
ASC_plane	2,143057093	0,312923188	6,848508446	7,46248E-12
B_Escalator_transfer	-0,755612434	0,176550082	-4,279875852	1,86998E-05
B_Lift_transfer	0,15799163	0,135801687	1,163399616	0,244667405
B_Stairs_transfer	0,045387576	0,1570297	0,289038163	0,772552173
B_delay_transfer	-0,025298659	0,013156808	-1,922856845	0,054498031
B_frequency_transfer	-0,126368202	0,129183618	-0,978206092	0,327972404
B_tc	-0,061656383	0,002692278	-22,90119732	0
B_transfertime	0,038266023	0,006543114	5,848288883	4,96655E-09
B_tt	-0,016150992	0,001031892	-15,65182699	0
B_tc_plane	-0,044505608	0,002758613	-16,1333272	0
B_transfertime	0,038285163	0,006544944	5,84957885	4,93E-09
B_tt	-0,016151475	0,001031965	-15,65118	0

Table D.2: Parameter estimates of the alternative travel time specific MNL model

	Value	Rob. Std err	Rob. t-test	Rob. p-value
ASC_car	-2,85948E-05	2,58481E-06	-11,06261638	0
ASC_directtrain	-2,57595E-05	5,59492E-06	-4,604086766	4,1428E-06
ASC_plane	-2,94266E-05	8,2418E-06	-3,570405044	0,00035643
B_Escalator_transfer	-0,755758029	0,176579831	-4,279979351	1,86911E-05
B_Lift_transfer	0,15836363	0,135811274	1,166056584	0,243591569
B_Stairs_transfer	0,045616747	0,157044997	0,290469279	0,77145725
B_delay_transfer	-0,025281086	0,013156884	-1,921510148	0,054667424
B_frequency_transfer	-0,126366807	0,129197259	-0,978092012	0,328028818
B_tc	-0,061663121	0,002693013	-22,8974445	0
B_transfertime	0,038285168	0,006544944	5,849578925	4,92819E-09
B_tt_Transfer	-0,016151475	0,001031965	-15,65118014	0
B_tt_car	-0,011580891	0,001046849	-11,0626163	0
B_tt_directtrain	-0,00695507	0,00151063	-4,604086717	4,1428E-06
B_tt_plane	-0,006620976	0,001854405	-3,570405027	0,00035643

Table D.3: Parameter estimates of the alternative travel cost specific MNL model

	Value	Rob. Std err	Rob. t-test	Rob. p-value
ASC_car	-0,000456564	3,577E-05	-12,763862	0
ASC_directtrain	-0,000355338	2,51829E-05	-14,1102683	0
ASC_plane	-0,000356045	2,20689E-05	-16,1333272	0
B_Escalator_transfer	-0,755757717	0,176579817	-4,27997791	1,87E-05
B_Lift_transfer	0,158363656	0,135811274	1,16605677	0,243591
B_Stairs_transfer	0,045617069	0,157044992	0,29047134	0,771456
B_delay_transfer	-0,025281086	0,013156883	-1,92151024	0,054667
B_frequency_transfer	-0,126366801	0,129197258	-0,97809197	0,328029
B_tc_Transfer	-0,061663119	0,002693013	-22,8974456	0
B_tc_car	-0,041090738	0,003219303	-12,763862	0
B_tc_directtrain	-0,039087129	0,002770119	-14,1102683	0
B_tc_plane	-0,044505608	0,002758613	-16,1333272	0
B_transfertime	0,038285163	0,006544944	5,84957885	4,93E-09
B_tt	-0,016151475	0,001031965	-15,65118	0

Table D.4: Parameter estimates of the MNL model with an interaction between delay and transfer time, continuous

	Value	Rob. Std err	Rob. t-test	Rob. p-value
ASC_car	1,885821556	0,40116588	4,700852318	2,59078E-06
ASC_directtrain	2,520977842	0,406888299	6,195749175	5,80084E-10
ASC_plane	2,183172945	0,435342872	5,01483563	5,30788E-07
B_Escalator_transfer	-0,760532263	0,179692875	-4,232400777	2,3121E-05
B_Lift_transfer	0,153156776	0,139077868	1,101230395	0,270796396
B_Stairs_transfer	0,046964531	0,156691264	0,299726545	0,764385749
B_delay_transfer	-0,020125458	0,040989709	-0,490988057	0,623434894
B_frequency_transfer	-0,123308904	0,132180558	-0,932882309	0,350880738
B_interaction_Delay_Transfertime_Transfer	-0,000195171	0,00145195	-0,134419751	0,893070664
B_tc	-0,061638955	0,00270796	-22,76213257	0
B_transfertime	0,039680776	0,012480167	3,179506723	0,001475259
B_tt	-0,016124144	0,001060382	-15,20598279	0

Table D.5: Parameter estimates of the MNL model with an interaction between delay and transfer time, dummy

	Value	Rob. Std err	Rob. t-test	Rob. p-value
ASC_car	1,901379742	0,336605716	5,648685247	1,6168E-08
ASC_directtrain	2,538729741	0,330418722	7,683371357	1,55431E-14
ASC_plane	2,198289545	0,354550094	6,200222705	5,63833E-10
B_Escalator_transfer	-0,807019205	0,222961873	-3,619539054	0,000295128
B_Lift_transfer	0,145486436	0,13793151	1,054773024	0,291529145
B_Stairs_transfer	0,059366381	0,160832837	0,369118537	0,712039373
B_delay_transfer	-0,03765286	0,036248024	-1,038756194	0,298918139
B_frequency_transfer	-0,07337324	0,196053873	-0,374250399	0,708218031
B_interaction_Delay_Transfertime_Transfer	0,158507845	0,441997837	0,35861679	0,719881785
B_tc	-0,061234587	0,002948163	-20,77042442	0
B_transfertime	0,041499449	0,01124242	3,691327031	0,000223087
B_tt	-0,016047953	0,001066878	-15,04197194	0

Table D.6: Parameter estimates of the MNL model with an interaction between frequency and transfer time

	Value	Rob. Std err	Rob. t-test	Rob. p-value
ASC_car	2,678184404	0,601920476	4,449399067	8,61109E-06
ASC_directtrain	3,662982367	0,782956465	4,678398518	2,89124E-06
ASC_plane	3,459050588	0,869282414	3,979202309	6,91469E-05
B_Escalator_transfer	-0,738955713	0,199014041	-3,7130833	0,000204749
B_Lift_transfer	0,092807116	0,141519063	0,655792334	0,51195775
B_Stairs_transfer	0,10312478	0,165596656	0,622746756	0,533450952
B_delay_transfer	-0,023877096	0,013154214	-1,81516711	0,069498232
B_frequency_transfer	1,232705765	0,767017526	1,607141589	0,108023312
B_interaction_Frequency_Transfertime_Transfer	-0,044778332	0,024610954	-1,81944724	0,068843226
B_tc	-0,063718367	0,003323203	-19,1737792	0
B_transfertime	0,071690962	0,021067227	3,402961454	0,000666597
B_tt	-0,013842446	0,001581008	-8,75545486	0

Table D.7: Parameter estimates of the MNL model with an interaction between frequency and delay

	Value	Rob. Std err	Rob. t-test	Rob. p-value
ASC_car	2,536372096	0,539469156	4,701607257	2,58122E-06
ASC_directtrain	2,99933023	0,4423703	6,780134722	1,20064E-11
ASC_plane	2,600254733	0,431841335	6,021319688	1,73001E-09
B_Escalator_transfer	-0,752442585	0,179082947	-4,201642866	2,64985E-05
B_Lift_transfer	0,541957489	0,289489622	1,872113708	0,061190874
B_Stairs_transfer	0,518627083	0,355311968	1,459638654	0,14438941
B_delay_transfer	0,035959705	0,041691442	0,862520046	0,388401407
B_frequency_transfer	0,57023728	0,487373447	1,170021232	0,241992425
B_interaction_Delay_frequency_Transfer	-0,123026597	0,082795924	-1,485901603	0,13730515
B_tc	-0,061171511	0,002673181	-22,88341527	0
B_transfertime	0,038528793	0,006519169	5,910077198	3,41947E-09
B_tt	-0,017330102	0,001310914	-13,21985921	0

Table D.8: Parameter estimates of the MNL model with an interaction between transfer time and cross-station transfer with lift

	Value	Rob. Std err	Rob. t-test	Rob. p-value
ASC_car	1,797928521	0,29875364	6,018097453	1,76479E-09
ASC_directtrain	2,402902037	0,293032327	8,200126115	2,22045E-16
ASC_plane	2,053094918	0,324134292	6,334087343	2,3875E-10
B_Escalator_transfer	-0,691803582	0,190729689	-3,627141567	0,000286576
B_Lift_transfer	-0,079010356	0,322328703	-0,245123549	0,80636077
B_Stairs_transfer	0,080558549	0,163810955	0,491777546	0,622876612
B_delay_transfer	-0,022894243	0,01330315	-1,720964103	0,085257338
B_frequency_transfer	-0,093790163	0,134258986	-0,698576427	0,48481678
B_interaction_Lift_transfertime_Transfer	0,009264441	0,011329764	0,817708227	0,413523812
B_tc	-0,061406076	0,002630816	-23,34107689	0
B_transfertime	0,034414186	0,007883328	4,365438647	1,26868E-05
B_tt	-0,016313432	0,001044904	-15,61237101	0

Table D.9: Parameter estimates of the MNL model with an interaction between transfer time and cross-station transfer with escalator

	Value	Rob. Std err	Rob. t-test	Rob. p-value
ASC_car	1,875116169	0,320317171	5,85393584	4,80074E-09
ASC_directtrain	2,513266	0,322048326	7,804002686	5,9952E-15
ASC_plane	2,179301645	0,356653495	6,110417191	9,9371E-10
B_Escalator_transfer	-0,58820966	0,775081155	-0,758900741	0,447911936
B_Lift_transfer	0,155164971	0,136347741	1,138009108	0,255116679
B_Stairs_transfer	0,03490238	0,16156979	0,21602046	0,828971799
B_delay_transfer	-0,02679335	0,014680516	-1,825095591	0,067986605
B_frequency_transfer	-0,10981872	0,145899314	-0,752702105	0,451628945
B_interaction_Escalator_transfertime_Transfer	-0,00555955	0,025323886	-0,219537648	0,826231256
B_tc	-0,06197969	0,003163791	-19,59032518	0
B_transfertime	0,039162299	0,007699626	5,086259743	3,65194E-07
B_tt	-0,01615233	0,001030167	-15,67933288	0

Table D.10: Parameter estimates of the MNL model with an interaction between transfer time and cross-station transfer with stairs

	Value	Rob. Std err	Rob. t-test	Rob. p-value
ASC_car	2,051117	0,425226	4,82359	1,41E-06
ASC_directtrain	2,686118	0,42436	6,329808	2,455E-10
ASC_plane	2,359109	0,459713	5,131699	2,871E-07
B_Escalator_transfer	-0,81991	0,206639	-3,96781	7,254E-05
B_Lift_transfer	0,17602	0,139243	1,264116	0,2061883
B_Stairs_transfer	0,458457	0,608068	0,753956	0,4508756
B_delay_transfer	-0,02175	0,013619	-1,59723	0,1102155
B_frequency_transfer	-0,10103	0,138241	-0,73079	0,4649094
B_interaction_Stairs_transfertime_Transfer	-0,01368	0,020042	-0,6826	0,4948611
B_tc	-0,06294	0,003364	-18,7121	0
B_transfertime	0,042725	0,009739	4,386916	1,15E-05
B_tt	-0,01632	0,001051	-15,5252	0

Table D.11: Parameter estimates of the MNL model with transfer time quadratic term

	Value	Rob. Std err	Rob. t-test	Rob. p-value
ASC_car	1,856848833	0,298188115	6,227105443	4,75131E-10
ASC_directtrain	2,484168903	0,283126337	8,774065052	0
ASC_plane	2,144797456	0,311108358	6,894052835	5,42255E-12
B_Escalator_transfer	-0,767926241	0,176483855	-4,35125491	1,35361E-05
B_Lift_transfer	0,162659962	0,135213064	1,202989985	0,228980196
B_Stairs_transfer	0,028369803	0,160624909	0,176621442	0,859805751
B_delay_transfer	-0,024955179	0,013180757	-1,89330385	0,058317473
B_frequency_transfer	-0,15211864	0,138449553	-1,098729729	0,271885971
B_tc	-0,061763848	0,002717047	-22,73197795	0
B_transfertime	0,036231035	0,007062789	5,129848101	2,89976E-07
B_transfertime_sq	9,68736E-05	0,00016235	0,596697135	0,550709606
B_tt	-0,016200655	0,001035168	-15,65025958	0

Table D.12: Parameter estimates of the MNL model with transfer time quadratic and cubic term

	Value	Rob. Std err	Rob. t-test	Rob. p-value
ASC_car	2,314347595	0,368432807	6,281600199	3,35106E-10
ASC_directtrain	2,858447966	0,342496415	8,345920834	0
ASC_plane	2,483752316	0,362442205	6,852823108	7,24065E-12
B_Escalator_transfer	-0,863653115	0,187368889	-4,609373094	4,03885E-06
B_Lift_transfer	0,024425906	0,140702961	0,173599087	0,86218055
B_Stairs_transfer	-0,182217182	0,175523329	-1,038136541	0,299206492
B_delay_transfer	-0,02519194	0,013108695	-1,92177334	0,054634284
B_frequency_transfer	-0,090826363	0,139864158	-0,649389839	0,51608643
B_tc	-0,06085411	0,002659054	-22,88562291	0
B_transfertime	0,036897363	0,007450138	4,952574322	7,32381E-07
B_transfertime_cu	-5,93467E-05	2,44703E-05	-2,425253462	0,015297702
B_transfertime_sq	0,002681168	0,001077115	2,489212916	0,012802627
B_tt	-0,016682334	0,001011912	-16,48595758	0

E

MNL with socio-demographics and travel habits interactions

E.1. Dummy coding

Table E.1: Dummy coding of the socio-demographic characteristics of the sample

Gender	**Gender**			
Male	0			
Female	1			
Age	**Age**			
18-30	0			
30+	1			
Work status	**Full_time**	**Student**		
Employee full-time	1	0		
Student	0	1		
Income	**Income_10k**	**Income_1030k**	**Income_3050k**	**Income_50100k**
Less than 10000 €	1	0	0	0
10000 to 30000 €	0	1	0	0
30000 to 50000 €	0	0	1	0
5000 to 100000 €	0	0	0	1
Driving license	**Driving_license**			
No	0			
Yes	1			

Table E.2: Dummy coding of the travel habits characteristics of the sample

Travel frequency	**Travel_Annual**	**Travel_Occasional**	**Travel_Regular**	**Travel_Frequent**
Annual	1	0	0	0
Occasional	0	1	0	0
Regular	0	0	1	0
Frequent	0	0	0	1
Mode used	**Use_Plane**	**Use_Train**	**Use_Car**	
Plane	1	0	0	
Train	0	1	0	
Car	0	0	1	
Railway transfer experience	**Railway_transfer_experience**			
No	0			
Yes	1			

E.2. Python code

```
#Import Biogeme and packages
import pandas as pd
import biogeme as biogeme
import biogeme.database as db
import biogeme.biogeme as bio
from biogeme import models
from biogeme.expressions import Beta, Variable
import os

#Read data
df = pd.read_excel(MNLmodel_UnA.xlsx')

#Define database
database = db.Database("Base_MNLmodel_UnA", df)

#Define variables names as python variables
globals().update(database.variables)

#Define general Beta parameters to be estimated
ASC_directtrain = Beta('ASC_directtrain',0,None,None,0)
ASC_plane = Beta('ASC_plane',0,None,None,0)
ASC_car = Beta('ASC_car',0,None,None,0)
B_tt = Beta('B_tt',0,None,None,0)
B_tc = Beta('B_tc',0,None,None,0)
B_transfertime_transfer = Beta('B_transfertime',0,None,None,0)
B_delay_transfer = Beta('B_delay_transfer',0,None,None,0)
B_Escalator_transfer = Beta('B_Escalator_transfer',0,None,None,0)
B_Stairs_transfer = Beta('B_Stairs_transfer',0,None,None,0)
B_frequency_transfer = Beta('B_frequency_transfer',0,None,None,0)

# Socio-demographics and travel habits interactions parameters
ASC_plane_Exp = Beta('ASC_plane_Exp',0,None,None,0)
ASC_car_Exp = Beta('ASC_car_Exp',0,None,None,0)
ASC_plane_ModePlane = Beta('ASC_plane_ModePlane',0,None,None,0)
ASC_car_ModeCar = Beta('ASC_car_ModeCar',0,None,None,0)
ASC_directtrain_Age = Beta('ASC_directtrain_Age',0,None,None,0)
ASC_directtrain_f = Beta('ASC_directtrain_f',0,None,None,0)
B_transfertime_transferGender = Beta('B_transfertime_transferGender', 0, None, None, 0)
B_ttIncome10 = Beta('B_ttIncome10', 0, None, None, 0)
B_tcIncome1030 = Beta('B_tcIncome1030', 0, None, None, 0)
B_tcExp = Beta('B_tcExp', 0, None, None, 0)

# Non-linearity parameters
B_transfertime_transfer_sq = Beta('B_transfertime_sq', 0, None, None, 0)
B_transfertime_transfer_cu = Beta('B_transfertime_cu', 0, None, None, 0)

# Transfer time square and cube terms
transfertime_transfer1_sq = transfertime_transfer1 ** 2
transfertime_transfer1_cu = transfertime_transfer1 ** 3
transfertime_transfer2_sq = transfertime_transfer2 ** 2
transfertime_transfer2_cu = transfertime_transfer2 ** 3

#Utilities
V1 =( B_tt * tt_transfer1 + B_tc * tc_transfer1 + B_transfertime_transfer * transfertime_transfer1 +
B_transfertime_transfer_sq * transfertime_transfer1_sq + B_transfertime_transfer_cu * transfertime_transfer1_cu
```

```
+ B_delay_transfer * delay_transfer1 + B_Escalator_transfer * Escalator_transfer1 + B_Stairs_transfer
* Stairs_transfer1 + B_frequency_transfer * Dummy_frequency_transfer1 + B_transfertime_transferGender
* transfertime_transfer1 * Gender + B_ttIncome10 * tt_transfer1 * Income_10k + B_tcIncome1030 *
tc_transfer1 * Income_1030k + B_tcExp * tc_transfer1 * Railway_transfer_experience )

V2 =( B_tt * tt_transfer2 + B_tc * tc_transfer2 + B_transfertime_transfer * transfertime_transfer2 +
B_transfertime_transfer_sq * transfertime_transfer1_sq + B_transfertime_transfer_cu * transfertime_transfer1_cu
+ B_delay_transfer * delay_transfer2 + B_Escalator_transfer * Escalator_transfer2 + B_Stairs_transfer
* Stairs_transfer2 + B_frequency_transfer * Dummy_frequency_transfer2 + B_transfertime_transferGender
* transfertime_transfer2 * Gender + B_ttIncome10 * tt_transfer2 * Income_10k + B_tcIncome1030 *
tc_transfer2 * Income_1030k + B_tcExp * tc_transfer2 * Railway_transfer_experience )

V3 =( ASC_directtrain + ASC_directtrain_Age * Age + ASC_directtrain_f * Travel_Frequent + B_tt *
tt_train + B_tc * tc_train + B_ttIncome10 * tt_train * Income_10k + B_tcIncome1030 * tc_train * In-
come_1030k + B_tcExp * tc_train * Railway_transfer_experience )

V4 =( ASC_plane + ASC_plane_Exp * Railway_transfer_experience + ASC_plane_ModePlane * Use_Plane
+ B_tt * tt_plane + B_tc * tc_plane + B_ttIncome10 * tt_plane * Income_10k + B_tcIncome1030 *
tc_plane * Income_1030k + B_tcExp * tc_plane * Railway_transfer_experience )

V5 =( ASC_car + ASC_car_Exp * Railway_transfer_experience + ASC_car_ModeCar * Use_Car +
B_tt * tt_car + B_tc * tc_car + B_ttIncome10 * tt_car * Income_10k + B_tcIncome1030 * tc_car * In-
come_1030k + B_tcExp * tc_car * Railway_transfer_experience )

#Associate utility functions with alternatives
V = 1: V1,2 :V2,3 :V3,4 :V4,5 :V5
#Associate availabilities with the alternatives
av = 1: av1,2: av2,3: av3,4: av4,5: av5

#Define MNL model
logprob = models.loglogit(V,av,CHOICE)

#Create Biogeme object
the_biogeme = bio.BIOGEME(database,logprob)

#Give name to model
the_biogeme.modelName = 'Base_MNLFinalwithsocio'

#Estimate model
the_biogeme . calculateNullLoglikelihood (av)
results = the_biogeme.estimate()

#Iterations
biogeme.saveIterations = True

#Get results in Panda table
PResults = results.getEstimatedParameters()
print(PResults)
print(results)
```

E.3. Results

Table E.3: Model performance of the MNL model with all socio-demographics and travel habits significant interactions

Model	Likelihood ratio test	AIC	BIC	Adjusted rho square
Base + all socio-demographics and travel habits	2263,97	2997,73	3159,36	0,4237

Table E.4: Parameter estimates of the MNL model with all selected socio-demographics and travel habits interactions with attributes

	Value	Rob. Std err	Rob. t-test	Rob. p-value
ASC_car	2,791115591	0,434099899	6,429661924	1,27888E-10
ASC_car_Exp	-0,934732378	0,314024519	-2,976622279	0,002914428
ASC_car_ModeCar	0,887220732	0,292343839	3,034853535	0,002406525
ASC_directtrain	2,669953784	0,347704273	7,678806356	1,59872E-14
ASC_directtrain_Age	0,417513891	0,161927699	2,578396981	0,009925989
ASC_directtrain_f	0,413513956	0,166665127	2,481106655	0,013097518
ASC_plane	1,776903892	0,454043928	3,91350656	9,09654E-05
ASC_plane_Exp	-0,297804547	0,233513339	-1,275321351	0,202195524
ASC_plane_ModePlane	1,353118198	0,219191818	6,173214913	6,69152E-10
B_Delay_TransferExp	-0,022790661	0,028823003	-0,790710842	0,429112748
B_Delay_TransferGender	0,020923827	0,024486347	0,854509964	0,392822491
B_Escalator_transfer	-0,885605311	0,191596294	-4,622246556	3,79606E-06
B_Stairs_transfer	-0,221901911	0,167996023	-1,320875976	0,186542721
B_delay_transfer	-0,022817976	0,02905762	-0,785266534	0,432297313
B_frequency_transfer	-0,160126778	0,242154108	-0,661259804	0,508445715
B_frequency_transferExp	0,074799214	0,249598876	0,299677688	0,764423019
B_tc	-0,057056513	0,005262988	-10,84108752	0
B_tcExp	-0,007627821	0,004625711	-1,649005317	0,099146545
B_tcGender	0,005568605	0,003575863	1,557275689	0,119405045
B_tcIncome1030	-0,010855675	0,003865554	-2,808310454	0,004980219
B_tcIncome50100	0,002926542	0,002938649	0,995879912	0,319308497
B_tcStudent	-0,003701074	0,002773329	-1,334524121	0,182032147
B_transfertime	0,044555317	0,010016983	4,447977764	8,66825E-06
B_transfertime_cu	-5,9556E-05	2,41397E-05	-2,467142205	0,013619626
B_transfertime_sq	0,002753625	0,001068073	2,578123089	0,009933861
B_transfertime_transferExp	-0,000226054	0,007550031	-0,029940762	0,976114297
B_transfertime_transferGender	-0,015157417	0,006844252	-2,214607141	0,026810518

F

Panel ML

F.1. ML code

```
#Import Biogeme and packages
import pandas as pd
import biogeme as biogeme
import biogeme.database as db
import biogeme.biogeme as bio
from biogeme import models
from biogeme.expressions import Beta, Variable„ bioDraws, PanelLikelihoodTrajectory, MonteCarlo,
log
import os

#Read data
df = pd.read_excel(MLmodel_UnA_R.xlsx’)

#Define database
database = db.Database(”Base_MLmodel_UnA_R”, df)

#Define variables names as python variables
globals().update(database.variables)

ID per individual to capture panel effect
database.panel(”ID”)

#Define Beta parameters to be estimated
ASC_Transfer = Beta(’ASC_Transfer’,0,None,None,1)
ASC_directtrain = Beta(’ASC_directtrain’,0,None,None,0)
ASC_plane = Beta(’ASC_plane’,0,None,None,0)
ASC_car = Beta(’ASC_car’,0,None,None,0)
B_tt = Beta(’B_tt’,0,None,None,0)
B_tc = Beta(’B_tc’,0,None,None,0)
B_transfertime_transfer = Beta(’B_transfertime’,0,None,None,0)
B_delay_transfer = Beta(’B_delay_transfer’,0,None,None,0)
#B_Lift_transfer = Beta(’B_Lift_transfer’,0,None,None,0)
B_Escalator_transfer = Beta(’B_Escalator_transfer’,0,None,None,0)
B_Stairs_transfer = Beta(’B_Stairs_transfer’,0,None,None,0)
B_frequency_transfer = Beta(’B_frequency_transfer’,0,None,None,0)

#Define panel random effects
ASC_transfer_std = Beta(’ASC_transfer_std’,0,None,None,0)
```

```
ASC_train_std = Beta('ASC_train_std',0,None,None,0)
ASC_plane_std = Beta('ASC_plane_std',0,None,None,0)
ASC_car_std = Beta('ASC_car_std',0,None,None,0)
ASC_transfer_random = ASC_Transfer + ASC_transfer_std *
bioDraws('ASC_transfer_random','NORMAL_MLHS')
ASC_train_random = ASC_directtrain + ASC_train_std *
bioDraws('ASC_train_random','NORMAL_MLHS')
ASC_plane_random = ASC_plane + ASC_plane_std *
bioDraws('ASC_plane_random','NORMAL_MLHS')
ASC_car_random = ASC_car + ASC_car_std * bioDraws('ASC_car_random','NORMAL_MLHS')

B_Escalator_transfer_std = Beta('B_Escalator_transfer_std',0,None,None,0)
B_Escalator_transfer_random = B_Escalator_transfer + B_Escalator_transfer_std *
bioDraws('B_Escalator_transfer_random','NORMAL_MLHS')

B_frequency_transfer_std = Beta('B_frequency_transfer_std',0,None,None,0)
B_frequency_transfer_random = B_frequency_transfer + B_frequency_transfer_std *
bioDraws('B_frequency_transfer_random','NORMAL_MLHS')

B_delay_transfer_std = Beta('B_delay_transfer_std',0,None,None,0)
B_delay_transfer_random = B_delay_transfer + B_delay_transfer_std *
bioDraws('B_delay_transfer_random','NORMAL_MLHS')

B_transfertime_transfer_std = Beta('B_transfertime_transfer_std',0,None,None,0)
B_transfertime_transfer_random = B_transfertime_transfer + B_transfertime_transfer_std *
bioDraws('B_transfertime_transfer_random','NORMAL_MLHS')

#Utilities
V1 =( ASC_transfer_random B_tt * tt_transfer1 + B_tc * tc_transfer1 + B_transfertime_transfer_random
* transfertime_transfer1 + B_delay_transfer_random * delay_transfer1 + B_Escalator_transfer_random
* Escalator_transfer1 + B_Stairs_transfer * Stairs_transfer1 + B_frequency_transfer_random *
Dummy_frequency_transfer1 )

V2 =( ASC_transfer_random B_tt * tt_transfer2 + B_tc * tc_transfer2 + B_transfertime_transfer_random
* transfertime_transfer2 + B_delay_transfer_random * delay_transfer2 + B_Escalator_transfer_random
* Escalator_transfer2 + B_Stairs_transfer * Stairs_transfer2 + B_frequency_transfer_random *
Dummy_frequency_transfer2 )

V3 =( ASC_directtrain_random + B_tt * tt_train + B_tc * tc_train )

V4 =( ASC_plane_random + B_tt * tt_plane + B_tc * tc_plane )

V5 =( ASC_car_random + B_tt * tt_car + B_tc * tc_car )

#Associate utility functions with alternatives
V = 1: V1,2 :V2,3 :V3,4 :V4,5 :V5
#Associate availabilities with the alternatives
av = 1: av1,2: av2,3: av3,4: av4,5: av5

# Contribution to the log likelihood function
obsprob = models.logit(V,av,CHOICE)
condprobIndiv = PanelLikelihoodTrajectory(obsprob)
logprob = log(MonteCarlo(condprobIndiv))

#Create the Biogeme object
the_biogeme = bio.BIOGEME(database,logprob, numberOfDraws=400)
```

```
#Give name to model
the_biogeme.modelName = 'ML_panel'

#Estimate model
results = the_biogeme.estimate()

#Get results in Panda table
PResults = results.getEstimatedParameters()
print(PResults)
print(results)
PCorrelations = results.getCorrelationResults() print(PCorrelations)
PGeneralStat = results.getGeneralStatistics() print(PGeneralStat)
```

F.2. ML results

Table F.1: Model performance of the ML model with all attributes selected to be tested for heterogeneity included

Model	Likelihood ratio test	AIC	BIC	Adjusted rho square
ML all attributes randomised	2577,78	2659,919	2719,468	0,4886

Table F.2: Parameter estimates of the ML model with all attributes selected to be tested for heterogeneity included

	Value	Rob. Std err	Rob. t-test	Rob. p-value
ASC_car	0.409446	0.523116	0.782707	4.337993e-01
ASC_car_std	-2.374659	0.313870	-7.565751	3.863576e-14
ASC_directtrain	2.431749	0.295150	8.239025	2.220446e-16
ASC_plane	0.534380	0.474790	1.125509	2.603733e-01
ASC_plane_std	-3.286739	0.493175	-6.664450	2.656586e-11
ASC_train_std	-1.180364	0.233358	-5.058174	4.232903e-07
ASC_transfer_std	-0.776016	0.305464	-2.540452	1.107093e-02
B_Escalator_transfer	-0.811755	0.208067	-3.901403	9.563674e-05
B_Escalator_transfer_std	-0.289521	0.491925	-0.588548	5.561647e-01
B_Stairs_transfer	0.162244	0.166353	0.975298	3.294127e-01
B_delay_transfer	-0.043180	0.015489	-2.787720	5.308045e-03
B_delay_transfer_std	0.042213	0.037852	1.115206	2.647623e-01
B_frequency_transfer	-0.261300	0.136091	-1.920040	5.485282e-02
B_frequency_transfer_std	-0.489715	0.302671	-1.617979	1.056672e-01
B_tc	-0.078000	0.004457	-17.500467	0.000000e+00
B_transfertime	0.037630	0.007178	5.242707	1.582378e-07
B_transfertime_transfer_std	0.004343	0.014732	0.294819	7.681320e-01
B_tt	-0.020311	0.001586	-12.802448	0.000000e+00