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# Relevance of detailed transfer attributes in large-scale multimodal route choice models for metropolitan public transport passengers 

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#### Abstract

Given the aim of increasing public transport patronage, it is important to understand how passengers perceive different trip characteristics. Most of the existing studies about public transport demand and route choice assigned a higher value of time to transfers than in-vehicle time and used a general transfer penalty to capture an average increase in the travel disutility because of the amount of transfers. However, it is likely that there are nuances to the transfer behaviour depending on specific transfer conditions that existing models do not capture and hence it is difficult to evaluate measures aimed at improving transfers to make public transport more attractive.

This study presents a route choice model for the large-scale multimodal public transport network in the Greater Copenhagen Region where a variety of transfer attributes were explicitly considered within a unified model framework. The model was estimated on an extensive revealed dataset of 4,810 observed routes that made it possible to evaluate the rates of substitution of transfer related attributes. The results revealed that travellers do consider attributes for transfers such as ease of wayfinding, presence of shops and escalators at stations when choosing routes in the public transport network and this influences the attractiveness of the respective routes with a quite large range of the transfer penalty from 5.4 minutes compared to bus in-vehicle time for the best possible transfer to 12.1 minutes for the worst. Furthermore, the study revealed some differences in the preferences for transfer attributes across passengers. This suggest a quite large potential for improving transfers and hence public transport patronage focusing on the attributes of the transfers.


## KEYWORDS

Multimodal, Public Transport, Route Choice, Transfer Penalty, Transfer Attributes, Stations.

## 1 INTRODUCTION

The attractiveness of public transport depends certainly on the services offered by the public transport agencies, but also on terminals and transfer conditions (Cascetta and Cartení, 2014). Public transport agencies may choose between a number of different suggestions to improve the terminals and thus create more attractive transfers. Supporting informed decisions on how to do this requires the understanding of travellers' preferences and route choice behaviour to be able to predict traffic flows and passenger benefits under different scenarios.

In a public transport network, travellers perceive time differently according to how time is spent. It is for example well known that most passengers prefer travelling by train rather than bus (Nielsen, 2000; Anderson et al., 2017, Fosgerau et al, 2007; Varela et al., 2018, Eluru et al 2012), as factors such as comfort and reliability are perceived as inherent mainly to travelling by train. It is also well known that a transfer in a public transport system not only adds disutility to the trip proportionally to the time spent on the transfer, but also includes a fixed disutility for each additional transfer on the trip, also known as transfer penalty. Previously, many public transport route choice models and value of time studies have revealed quite large transfer penalties varying between 5 and 20 minutes of in-vehicle time (Van der Waard, 1988, Vrtic \& Axhausen, 2003, Bovy \& HoogendoornLanser, 2005, Nielsen, 2004, Nielsen \& Frederiksen, 2006, Eluru et al. 2012, De Grange et al. 2012), where the penalties added a fixed disutility regardless of the characteristics of the transfer stations or terminals.

In recent years, different studies have focused on exploring the differences of the experienced penalty of transferring by considering transfer related characteristics. Iseki and Taylor (2009) described the importance of modelling transfer penalties and suggested that three factors are key contributors: (i) operational factors that influence the waiting time at the terminal, (ii) physical facilities at the terminal such as safety and security measures as well as facilities to provide comfort such as correct signing and shelters, and (iii) factors relating to passengers' familiarity with the network. For unimodal (metro) networks, Raveau et al. (2011), Guo and Wilson (2011) and Raveau et al. (2014) estimated the effect of attributes such as escalator presence, differences in platform levels and ramp lengths, as well as network knowledge of the passengers. For multimodal networks, Chowdhury and Ceder (2013) and Chowdhury et al. (2014) looked at the effect of attributes such as transfer information, real-time display and security measures; Navarrete and Ortúzar (2013) estimated the effect of intermodal transfers (bus/metro) and escalator presence at transfers; Schakenbos et al. (2016) took a more aggregate approach defining different typical transfer stations based on shop availability; Anderson et al. (2017) modelled the effect of intermodal transfers; and Garcia-Martinez et al. (2018) modelled intermodal transfers, real-time information and difference in levels when transferring.

All the multimodal studies were based on surveys, including stated preference (SP) surveys, while most unimodal studies were based on observed trips. For the unimodal studies, Gou and Wilson (2011) mentioned that it was difficult to obtain detailed data about the transfer attributes, and Raveau et al. (2011) mentioned that a limitation of their study was the unimodality and hence the inability to describe the full journey, which in many cases consisted of combinations of legs with bus, train and/or metro. The limitation of unimodality has been approached in the multimodal studies (Chowdhury and Ceder, 2013, Chowdhury et al., 2014, Navarrete and Ortúzar, 2013, Schakenbos et al., 2016, Anderson et al., 2017, Garcia-Martinez et al., 2018), but none of these studies have tackled the issue of obtaining detailed data about the transfer attributes, as they have used SP surveys to estimate their effect.

The aim of this study is thus to analyse in detail the components of transfer penalties by modelling observed route choices in a multimodal network and collecting relevant transfer attributes of the respective transfer terminals. The analysis was performed on the multimodal public transport network of the Greater Copenhagen Region, which is served by metro, three different train services
(local, regional and suburban) and bus services. The analysis focused on revealed preferences by modelling 4,810 actual route choices that were collected and map-matched for all trips with both start and end in the Greater Copenhagen Region (for details, see Anderson, 2013).

The relevance of the transfer attributes to the route choices of travellers was investigated via the estimation of route choice models with different formulations to capture the effects of transfer attributes on passenger preferences. Choice sets were generated via a doubly stochastic generation method (Nielsen, 2004; Rasmussen et al., 2016) that produced up to 200 alternative routes to each observed route. Most importantly, the estimation of route choice models considered several specifications given the exploratory nature of the study and the absence of reference values for the sensitivity to transfer attributes. The applications of the findings are as follows: (i) they can be applied to suggest effective improvements to existing transfer stations with the aim of decreasing the disutility of public transport trips, (ii) they can be applied to provide design guidelines to new transfer stations, and (iii) they can improve route choice models for public transport enabling them to evaluate overall passenger effects of improved public transport terminals.

The remainder of this paper is structured as follows. Section 2 introduces the transfer attributes and their measurement. Section 3 provides the description of the methodology and Section 4 presents the case-study. Section 5 illustrates the results prior to the last section discussing the results and giving recommendations about the conclusions from the findings of the study.

## 2 SELECTION AND DEFINITION OF TRANSFER ATTRIBUTES

As aforementioned, several studies in the past decade have focused on unraveling passenger preferences while considering the characteristics of the transfer terminals. Table 1 summarizes the transfer attributes considered in these previous studies and differentiates whether the attributes have been estimated or just mentioned as possibly considered in the route choice. All the attributes in table 1 can potentially be relevant to the passengers' route choices, but the data availability and the variable definition possibility for modelling purposes can be critical. The process of selecting the most important variables for passengers' route choice and the possible definition of the variables is described below.

Table 1. Transfer attributes in previous studies (attributes with an $\mathbf{X}$ have been estimated, while attributes with an (x) have only been mentioned)

| Study |  |  |  | $\begin{aligned} & \frac{2}{\#} \\ & \frac{0}{0} \\ & \frac{0}{6} \end{aligned}$ |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Anderson (2013) |  |  |  |  |  |  |  | (x) |  |  |  |
| Chowdhury and Ceder (2013) |  |  |  |  | X | X | X |  |  |  |  |
| Chowdhury et al. (2014) |  |  |  | X |  | X |  |  |  | (x) |  |
| Garcia-Martinez et al. (2018) | X |  |  |  | X |  |  |  |  |  |  |
| Gou and Wilson (2011) | X | X | X |  |  |  |  |  |  |  |  |
| Iseki and Taylor (2009) | (x) | (x) |  | (x) | (x) | (x) | (x) |  | (x) |  | (x) |
| Navarrete and Ortúzar (2013) |  | X |  |  |  | X |  |  |  |  |  |
| Raveau et al. (2011) | X | X |  |  |  |  |  |  |  |  |  |
| Raveau et al. (2014) | X | X |  |  |  |  |  |  |  |  |  |
| Schakenbos et al. (2016) |  |  |  |  |  |  |  | X |  |  |  |

### 2.1 Selection and definition of transfer attributes to be estimated

Since the data for this paper is from the period 2009-2011, real-time information was not included in the long-list of variables to consider and also ramp length was disregarded as it would almost only be present for transfers to and from metro services in the Greater Copenhagen network. With the aim of finding the most suitable attributes to consider for the estimations, the remaining eight attributes from table 1 were then evaluated in further detail with regard to four criteria: validity, reliability, measurability, and data availability (Dyrberg \& Christensen, 2015).

The validity criterion defined how well an attribute measures the phenomenon. In this case, how much impact the attribute has on the transfer. The reliability criterion evaluated how objective the measure of the attribute can be: ideally, two independent measures of the same attribute under the same circumstances would give the same result, but this might be a problem when measuring more qualitative attributes. The measurability criterion assessed how easy to measure each of the eight attributes are. The data availability checked how demanding the data collection would be for each attribute (Joumard et al., 2010).

Table 2 shows the long-list of eight attributes along with the evaluation over each criterion. Shelters, shops and level changes were rated as "high" on all four criteria and were all included in the short-list of attributes to collect data for. Seat availability at a transfer performed rather well in all criteria except for validity, due to the fact that travellers do not always use seats. Furthermore, this attribute would probably be correlated with the attribute representing shelters. Occupancy scored well in several criteria without making it to the short-list, mainly due to poor data availability of our study. Ease of wayfinding was rated as "high" or "medium" for all criteria, and despite the fact that this attribute has some issues especially on the reliability criterion, it was considered to be highly valid
and was therefore included in the short-list. The attributes appearance and safety were both disregarded as they were rated as "low" in terms of validity and measurability. Security was also disregarded, as it would be difficult to measure considering the "medium" validity and measurability.

Data were then collected for the four attributes shelters, shop availability, level changes and ease of wayfinding. However, during the estimation of the route choice models, the shelter attribute was found to be non-significant regardless of the model specification and hence the attribute is not discussed further. The data collection and specification for shop availability, level changes and ease of wayfinding follows below.

Table 2. An overview of how each attribute has been rated according to the four criteria

|  | Validity | Reliability | Measurability | Data availability |
| :--- | :--- | :--- | :--- | :--- |
| Appearance | Low | Low | Low | Low |
| Seats | Medium | High | High | Low |
| Safety | Low | Low | Low | Medium |
| Security | Medium | Medium | Medium | Medium |
| Shop availability | High | High | High | High |
| Level changes | High | High | High | High |
| Shelters | High | High | High | High |
| Ease of wayfinding | High | Medium | Medium | Medium |

## Shop availability

Three levels of shops were considered to capture shop availability at a given transfer: (i) no shop; (ii) a kiosk; (iii) several shops. No shop was defined as a transfer without access to any kind of shop. This is often the case for bus-bus transfers away from stations. A kiosk was defined as a transfer with access to a small shop where it is possible to buy snacks, drinks, magazines, tickets etc. Many suburban train (S-train) stations have at least a kiosk. Several shops were registered when there is more than a kiosk, for example a grocery store, a bakery or any other type of shops. Some stations have a shopping mall right next to the station and transfers here are registered with several shops, since there is direct access to the shopping mall from the station.

## Ease of wayfinding

Ease of wayfinding describes how easy it is to find the direction from the stop where the traveller arrives to the stop where the next transport mode is departing. Notably, the information level can affect the perceived and actual transfer walk time (Iseki and Taylor, 2009). As a longer walk exposes the travellers to more situations where they risk taking the wrong turn or getting lost, the two parameters are considered somewhat correlated. The ease of wayfinding was divided into four categories, where each category was defined as a dummy since a transfer could only be within one of the four categories: (i) easy; (ii) low difficulty; (iii) moderate difficulty; (iv) difficult.

Easy was defined as a transfer where it is straightforward to find the direction between the arriving and the departing stop, as the information level is good and the departing stop can be found
intuitively. An example could be a transfer from one train to another where the two trains arrive at and depart from the same platform.

Low difficulty described transfers where it takes more than a few seconds to find the direction for the next departing stop, but then it is still quite simple to find the departing stop given the information signs. The distance from the arriving stop to the departing stop is often relatively short because it is somewhat correlated to the number of times a traveller risks getting lost.

Moderate difficulty indicated transfers where it is more difficult to find the right direction towards the next departing stop and, once the direction is found, there are still risks of getting lost on the way. Moderate difficulty often includes transfers where the distance between the arriving stop and the next departing stop requires walking for several minutes, consequently increasing the risk of getting lost. Another possible transfer with moderate difficulty is when finding the direction corresponds to low difficulty but once the departing area is reached, it is confusing to understand where the specific line is departing from. An example is finding the correct bus stop at a larger terminal with many buses, finding the right platform for a specific train when there are many platforms to choose from, or other similar situations.

Very difficult defined transfers where the information level is low and/or the travellers find it very difficult to find the direction when transferring from an arriving stop to the next departing stop, and it may be confusing where the specific line is departing from. The traveller risks getting lost more than once after locating the departing stop, or facing many options when it comes to finding the correct way. Only few transfers in the case study presented below were characterized as being very difficult.

## Level changes

The number of level changes per transfer corresponded to the number of times a traveller has to ascend or descend stairs. Furthermore, it recorded whether escalator assistance was available for the ascend or descend, and if so the escalators were assumed to be used. The case study area does not include stations with more than approximately three storeys vertical difference and hence the vertical height differences was captured by counting the number of ascending and descending stairs and escalators. The number of ascends and descends at transfer stations were summed for the whole alternative route, and since a general transfer penalty is included in the models, the number of ascends and descends with and without escalators describes the difference to transfers without level changes.

## 3 ROUTE CHOICE MODELS

Passenger preferences were estimated within a discrete choice modelling framework after generating a choice set for each of the observed routes and retrieving information about trip components and attributes of the transfer stations.

### 3.1 Model formulation

A random utility model assuming that each traveller $n$ maximises his or her utility by choosing route $i$ among a possible set $C_{n}$ of routes is assumed. The deterministic part $V_{n i}$ of the random utility $U_{n i}$ for each route is formulated as a linear-in-parameter function (Ben-Akiva \& Lerman, 1985).

In a multi-modal public transport network, travellers choose their route among a number of alternatives that might overlap to some extent. Bovy and Hoogendoorn-Lanser (2005) also modelled route choice behaviour in multi-modal transport networks. They dealt with this by nested logit structures. However, this was for intercity transport between 9 station in Rotterdam and 5 stations in Dordrecht, where all trips were with train between, and the nested model hereby could consider the conditional choice of access and egress mode to train, which reduced the nest to 8 alternatives and 3 values of time (for access transit, train and egress transit). Prato et al (2017) also investigated such a conditional choice dependent on the main mode being rail.

In the multimodal setting in the present study, we distinguish between access and egress, as well as explicitly between chains of 5 separate transit sub-modes (bus, local train, metro, urban (S) train, and regional/intercity train). A nesting structure of this would be enormous, with 5 alternatives for direct trips, 25 alternatives for one-transfer trips, 125 alternatives for two-transfer trips, and 29 trips with more transfers (refer to section 4.2 for further details). In the Copenhagen case to be presented in the following, only $14.4 \%$ of the trips used local, regional or intercity train (as compared to Bovy and Hoogendoorn-Lanser, 2005, who only considered trips including train). The public transport networks contains 1,718 multi-modal transfer options. Further, with 4,444 bus-terminals and 227 stations of different types, the enumeration of alternatives to capture correlation between terminals in a GEV-choice model would be very complex. Accordingly, the probability was instead formulated according to a Path Size Correction (PSC) Logit model by considering the length of the common links between routes (Bovy et al., 2008)

$$
P_{n i}=\frac{\exp \left(V_{n i}+\beta_{P S C} \cdot P S C_{i}\right)}{\sum_{l \in C_{n}} \exp \left(V_{n l}+\beta_{P S C} \cdot P S C_{l}\right)}
$$

where $P S C_{i}$ is the Path Size Correction factor for route $i$, and $\beta_{P S C}$ is the parameter to be estimated. $P S C_{i}$ is given by the following expression (Prato, 2009):

$$
P S C_{i}=-\sum_{a \in \Gamma_{i}}\left(\frac{L_{a}}{L_{i}} \ln \sum_{l \in C_{n}} \delta_{a l}\right)
$$

where $L_{a}$ is the length in minutes of link $a$ between stops, $L_{i}$ is the length in minutes of route $i, \Gamma_{i}$ is the set of links belonging to route $i, \delta_{a l}$ is the link and route incidence dummy equal to one if route $i$ uses link $a$ and zero otherwise. The Path Size Correction factor varies from $-\infty$ to 0 , where 0 represents a completely independent route.

Heterogeneity across travellers was considered with the estimation of a Mixed PSC Logit model. The density distribution for each of the parameters were considered as being either normally or log-normally distributed (as in Anderson et al 2017), and the probability $P_{n i}$ of traveller $n$ choosing alternative route $i$ within the choice set $C_{n}$ was expressed as:

$$
P_{n i}=\int \frac{\exp \left(V_{n i}\right)}{\sum_{l \in C_{n}} \exp \left(V_{n l}\right)} f(\beta) d \theta
$$

where the probability is integrated over the distributions of the $\theta$ 's, which can be either entered in the model as non-distributed, lognormal distributed or normal distributed parameters.

The lognormal distribution was used in the final model. Besides providing the best model fit in the specific case, this distribution secure that all link-costs are positive. The schedule-based choice set generation model (Rasmussen et al, 2016), and practical assignment models use an event dominance modification of a Dijkstra algorithm for efficient path search, where one of the preconditions are additive and positive link-costs (Nielsen \& Frederiksen, 2006 \& 2008). Further, if a given parameter for some variable has illogical sign, this would mean that the generalized cost could decrease passing certain links, which could lead illogical chosen paths. The ratio of two lognormal distributions is also lognormal, whereby the rate of substitutions are well behaved, which is an additional benefit of this distribution.

All models were estimated using PythonBiogeme (Bierlaire, 2016) and the probabilities of the Mixed Logit models were simulated with 500 draws for the final models. To test whether the extra transfer related variables and allowing heterogeneity across travellers give a significant better model fit the likelihood ratio test (LRT) is used. The test statistic is chi-squared distributed and takes into account the number of restricted parameters in the restricted model compared to the unrestricted model.

$$
L R T=-2\left|\mathcal{L}_{R}(\hat{\theta})-\mathcal{L}_{U}(\hat{\theta})\right| \sim X_{D O F}^{2}
$$

The following subsection introduces the model specification of the base model, which is a restricted model of the model including transfer related variables.

### 3.2 Model specification

It is well-known from the literature that time and cost are very important for public transport travellers. Previous studies have included various time components, namely in-vehicle time, access/egress time, and transferring time (waiting/walking), as the main descriptors of the passengers' route choices together with a general transfer penalty (van der Waard, 1988, Nielsen, 2000, Bovy and Hoogendoorn-Lanser, 2005, Tørset, 2005, de Grange et al.,2012, Eluru et al., 2012). Fare and/or frequency of the lines are also commonly used parameters in the models (Vrtic and Axhausen, 2003, Abrantes and Wardman, 2011, Navarrete and Ortúzar, 2013, Schakenbos et al., 2016).

In this study, the first and last part of a trip using public transport is always by walking or bicycle when considering the trip at the address level. The access and egress time used to the public transport network can be a considerable part of the total trip and is perceived as a disutility which the travellers seek to minimize and can be modelled in great detail as seen in for example Park et al. (2015). For this study, the level of information about the access and egress is only based on the time it took and whether it was made by walking or cycling. The access and egress times were therefore calculated via a simple regression model that takes into account that longer access/egress trips are typically made by bike compared to shorter access and egress legs (Anderson, 2013).

The in-vehicle travel time is also a factor that the passengers try to minimize, and the literature indicates that they do not perceive travel time in different public transport sub-modes to be the same. For example, many studies (Nielsen, 2000, Anderson et al., 2017, Fosgerau et al, 2007, Varela et al.

2018, Eluru et al 2012) found that travellers prefer trains to buses (more than can be explained by the higher frequencies, faster travel time, etc.).

In public transport network representations, there is in all systems a hidden waiting time that captures the fact that passengers cannot always time their departure to the first stop or the arrival to the destination at their preferred time. To capture this in the model, the least frequent service in the route is used as an indicator of the hidden waiting time for the route. This variable is defined as half of the headway of the least frequent service of the route, which was also found to be a good indication of the hidden waiting time in Anderson (2013).

Although fares and prices have been considered relevant in many studies, this is not a parameter to include for the case-study considered. The fare structure in the case-study area is zone-based and the price of the trip is based on the furthest away zone visited during the trip. This will in almost all cases, with very few exceptions, be the destination zone, and hence the price for the trip will be the same no matter which route is taken. Also, there are no price difference for the specific sub-modes used or extra costs associated to transferring between services. Hence, it was decided not to include the price of the trip in the analysis.

In section 5, the results of a model including these well-known descriptors will be used as a baseline model, which is then extended with the selected transfer attributes from section 2 . The chosen specifications of these new attributes are presented in section 5.2.

## 4 CASE-STUDY

### 4.1 The multimodal public transport network

The study analysed the multi-modal public transport network of the Greater Copenhagen Region that includes metro, urban rail (so-called S-trains), local trains, regional trains and busses. The main train corridors in the Greater Copenhagen Region are radial, going out from Copenhagen (see Figure 3). Only one circular train line is operated and this is located rather close to the Copenhagen centre and high frequent express busses serve the circular roads further away. The Strains are operated with 5-10 minutes headways, the metro with $1 \frac{1}{2}-3$ minutes, and the regional trains have headways varying from 20 to 120 minutes. Busses near the Copenhagen Central Business District (CBD) have headways of 3-10 minutes and busses in the outskirts of 20-60 minutes. No denied boardings or excessive overcrowdings were observed in the network at the time of the data collection. The Region has a population of about 2 million people and is the most densely populated area in Denmark.

The network structure is complex and a public transport trip between two points often has several competing route alternatives consisting of different transport sub-modes, transfer terminals, in-vehicle times, transfer times, etc. The network database originates from the Danish National Model (NTM) (also described in Anderson et al., 2017). This is a schedule-based network consisting of 369 public transport lines with a total of 18,487 daily runs, 4,660 stop groups ( 4,441 bus stops, 77 local train stations, 22 metro stations, 85 urban (S) train stations, and 35 regional/intercity train stations) with 1,718 between-mode transfer options (multi-modal transfers). The stop groups are represented by nodes and consists of closely located stops served by one or several lines of the same type, for example two bus stops at each side of a two-way road. The transfers in NTM are described by transfer
edges between the stop groups with a transfer walking time depending on the length of the edge and transfer waiting time in the final node. For this study, the transfers were considered in more details as described in section 4.3.

### 4.2 Revealed preference survey

The observed routes were collected by Anderson (2013) as part of the Danish Travel Survey. The travel survey collected information about actual trips from a representative sample of the Danish population between 10-84 years. The respondents were asked to describe in details all their trips conducted at a specific day with both private and public transport modes. Anderson (2013) mapmatched the details of the observed trips to the GIS network described above by identifying the actual public transport lines, bus stops, train stations and schedules used by the traveller. As described in Anderson (2013), not all of the observations were possible to match to timetable. Since the observations was matched to a planned timetable for a representative day, some observations were also discarded since the reported and matched times did not correspond, which could be due to timetable changes on the specific day of the observation or large delays in the network. The dataset used in this study consists of 4,810 observed trips and routes in the public transport network. The purpose of the observed trips was also collected and the trips were divided into two main purposes: 2,553 work related trips (commute and work trips) and 2,257 leisure trips.

The observed trips are mainly using the radial fingers of the network, with some trips using the different combinations of lines crossing the city. As seen in Figure 1, the trips are expectedly distributed across the day, with the work related trips following the typical pattern of outbound trips in the morning and homebound trips in the afternoon. The leisure related trips are primarily taking place between 10 am and 6 pm , but also with some trips departing in the evening hours. We did not explore time of day as a separate variable due to this strong correlation with trip purpose.


Figure 1 - Density plots for the departure times of respectively work and leisure related trips

Most of the observed trips are direct trips with no transfers ( 2,787 trips - hereof $41 \%$ using bus, 35 using S-train, $11 \%$ using local, regional or IC train and $12 \%$ using metro). The rest of the trips include transfers and 1,668 trips have a single transfer (refer to table 3 for the distribution), 326 trips have two transfers ( $25 \%$ Bus-S-Train-Bus, 15\% Bus-S-train-Metro, 13\% Bus-S-train-S-train, $12 \%$ Bus-Local/Reg/IC-S-train, 36\% other combinations) and 28 trips have three transfers. Only a single observation has four transfers.

Table 3. Transport modes used on observed trips with one transfer (1,668 trips)

| Between <br> transport modes | Bus | S-Train | Local, <br> Regional, IC | Metro |
| :--- | :---: | ---: | ---: | ---: |
| Bus | $18.3 \%$ | $25.8 \%$ | $7.9 \%$ | $10.8 \%$ |
| S-Train |  | $8.9 \%$ | $6.3 \%$ | $17.8 \%$ |
| Local, Regional, IC |  |  | $1.0 \%$ | $2.3 \%$ |
| Metro |  |  |  | $0.8 \%$ |

The headways in the model area are, as outlined above, in general low, which also results in low waiting times per transfer. The average waiting time for observed transfers is around 7 minutes and few observations have an average waiting time per transfer of more than 10 minutes as seen in Figure 2. Most observations have low average waiting times per transfer of less than five minutes and
many of the observations have zero minute waiting times giving a perfect coordination in the correspondence between services.


Figure 2 - Histogram of average waiting time per transfer per observation for the two trip purposes

Information about the non-chosen alternatives for each traveller was also needed in order to estimate the route choice models. The method used is based on repeated searches for the shortest path, where impedances are randomly drawn from a distribution in a doubly stochastic generation function (Nielsen, 2004). The choice set in Anderson (2013) was generated with 200 iterations after which the routes that were not unique or coincided with the actual chosen route were removed from the choice set, providing choice sets with 18-200 alternative routes for the respective observed routes. Rasmussen et al. (2016) investigated the robustness of this choice set generation procedure for model estimation purposes for the same case study. The reader is referred to the two mentioned studies for further details of the generated choice sets as these have been reused in the present study. However, it should be mentioned that for the purpose of this study further tests were conducted to check the removal of some irrelevant alternatives. This was, however, not found to significantly improve the model fits, which is in line with the finding in Rasmussen et al. (2016) that a large choice set is superior to a choice set with some relevant alternatives missing.

### 4.3 Data collection of transfer attributes

Information about all stations in the Greater Copenhagen Region were collected in order to assign the correct attributes to each station and thereby determine the design of each transfer. The
stations were divided into two groups, where the first included the 20 largest transfer stations with the attached bus stops and the second included the remaining stations and bus stops.

The 20 largest transfer stations cover $65 \%$ of all transfers in the observed data and each of these have been examined for very detailed information about every possible transfer. All of these transfer stations had transfers between rail and one or several groups of bus stops. Two stations served only metro, seven only S-train (urban train) but all serving several lines, five both S-train and regional train, two both metro and S-train, one both regional and local train, two both S-train and local train, and one both S-train, Regional-Train and metro. Three of the stations where underground in the city centre, nine other located in the city centre, five in suburbs, and three in neighbouring towns within the region. The map in Figure 3 illustrate the location of these stations. Dyrberg \& Christensen (2015), section 5.1.2, contains detailed information on these stations.


Figure 3-The 20 largest transfer stations in Greater Copenhagen Area, with number of observed routes per station in the national transport survey (Dyrberg \& Christensen, 2015).

For the remaining $35 \%$ of the transfers a more general method was used to determine the transfer attributes. The stops for each sub-mode were divided into several categories explaining the
transfer attributes for the specific stop: bus (two groups), metro (four groups), S-train (eight groups), regional/intercity train (seven groups), local train (two groups). The data was collected by using Google Street View, personal knowledge of the network and visits to some of the stations. All the variables included in the final model are summarised in table 4 , which includes descriptive statistics about the number of routes, which include the specific variable.

From the collected data on transfer attributes, it is also possible to investigate the correlation between specific transfer attributes on the transfers in the network, which is important to investigate as mentioned in Hoogendorn-Lanser et al. (2006). Figure 4 shows the correlation between the collected transfer attributes on the different transfers in the network. Many of the correlations are intuitive, for example that the number of ascends and descends is positively correlated since many transfers involve a footbridge or tunnel to connect the stops and hence both an ascend and a descend. The positive correlation between the easy wayfinding and respectively no level changes and no shops at the transfer is also intuitive, but importantly these correlations are not critically high being respectively 0.31 and 0.24 . The negative correlations between the variable for no level changes and the variables for stairs and escalators are the result of many of the transfers having one of the attributes, but all others are then non-existing for the other variables and hence there is a negative correlation with the "no level change" variable. For the shopping variables, a similar pattern appears, where the transfers with several shops do not just have one shop, and hence there is a high negative correlation between these variables. It is noticeable that the very difficult wayfinding is not significantly correlated with any of the stairs and escalator variables, which indicates that the definition of the very difficult transfers is able to distinguish itself from just reflecting ascends and descends.


Figure 4 - Correlation between the transfer attributes for the transfers in the network (color indicates correlation and non-significant correlations are marked with the associated p-value)

Table 4. Descriptive statistics for the observed routes

|  | Work <br> Mean <br> Std. dev. <br> (For obs. <br> incl att.) |  |  | (For obs. <br> incl att.) | Mean <br> Obs. incl. <br> attribute | Leisure <br> (For obs. <br> incl att.) |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: |
| Parameters | (For obs. <br> incl att.) | Obs. incl. <br> attribute |  |  |  |  |
| Time components |  |  |  |  |  |  |
| Bus (min.) | 15.81 | 10.80 | 1,278 | 14.96 | 11.34 | 1,229 |
| Local train (min.) | 19.27 | 10.81 | 83 | 20.99 | 13.80 | 69 |
| Metro (min.) | 7.16 | 4.80 | 541 | 6.96 | 5.10 | 445 |
| Reg. train (min.) | 23.66 | 12.44 | 355 | 23.48 | 13.60 | 192 |
| S-train (min.) | 17.15 | 12.44 | 1,317 | 16.31 | 12.05 | 937 |
| Access (min.) | 6.97 | 6.11 | 2.553 | 5.97 | 5.43 | 2,257 |
| Egress (min.) | 7.00 | 6.48 | 2,553 | 6.37 | 6.90 | 2,257 |
| Transfer attributes |  |  |  |  |  |  |
| Walking time | 2.97 | 1.32 | 1,043 | 2.91 | 1.35 | 620 |
| Waiting time | 6.81 | 7.51 | 1,069 | 7.69 | 9.79 | 687 |
| Number of transfers | 1.20 | 0.44 | 1,228 | 1.18 | 0.42 | 795 |
| Ease of wayfinding transfers |  |  |  |  |  |  |
| Easy | 1.05 | 0.22 | 484 | 1.09 | 0.28 | 267 |
| Little difficulty | 1.07 | 0.26 | 685 | 1.08 | 0.29 | 444 |
| Moderate difficulty | 1.03 | 0.16 | 195 | 1.02 | 0.15 | 135 |
| Difficult | 1.00 | 0.00 | 31 | 1.00 | 0.00 | 33 |
| Shop level |  |  |  |  |  |  |
| Shop av. at any transfer | 1.00 | 0.00 | 1,106 | 1.00 | 0.00 | 686 |
| Level changes |  |  |  |  |  |  |
| Ascending stairs at transfers | 1.14 | 0.36 | 456 | 1.13 | 0.37 | 267 |
| Descending stairs at transfers | 1.13 | 0.34 | 478 | 1.13 | 0.34 | 289 |
| Ascending escalators at transfers | 1.28 | 0.45 | 259 | 1.33 | 0.48 | 158 |
| Descending escalators at transfers | 1.36 | 0.50 | 250 | 1.39 | 0.50 | 140 |
| Overall measures |  |  |  |  |  |  |
| Half of highest headway in trip | 6.87 | 9.20 | 2,553 | 7.23 | 7.87 | 2,257 |
| Total trip time | 40.22 | 19.61 | 2,553 | 34.31 | 21.74 | 2,257 |
| Crow flies distance | 13.00 | 10.47 | 2,553 | 9.77 | 10.11 | 2,257 |
| Number of observations |  | 2,553 |  |  | 2,257 |  |

## 5 RESULTS

This section first presents a base model where none of the transfer attribute variables are included. This is followed by the presentation of the model with the best specification of transfer related attributes. Finally, we present a model that allows for heterogeneity in passenger preferences, based on the model with the best specification of transfer attributes.

### 5.1 Base model

Table 5 shows for comparison a base model similar to Anderson et al. (2017), estimated with reasonable sizes and signs for in-vehicle time (IVT), number of transfers, waiting and walking time at transfers.

Both the base model and the model with transfer related attributes included were estimated with a path-size factor. However, since the model with transfer related variables yielded a non-significant path size correction term (PSC), only the results of the models without the PSC-term are presented to ease comparisons between the models. The PSC would normally correct for overlapping routes in a way where utilities for overlapping routes are reduced. However, some studies of public transport have showed negative estimates for path-size terms (Hoogendoorn-Lanser \& Bovy, 2007, Anderson et al. 2017, De Grange et al, 2012), most likely because this corresponds to having more opportunities to reach their destination from their origin. Given the inherent risk of delays and irregularity in public transport networks, travellers might simply value the availability of a large number of en-route alternative options over the uniqueness of the route (Anderson et al. 2017). The non-significance of the PSC in the present study may indicate a balance between normal correction of overlapping routes by the inclusion of transfer related variables. Big terminals are e.g. usually less easy for wayfinding (a variable in the models) at the same time as they typically serves more routes than smaller terminals. This variable is hence somewhat correlated with the degree of path overlap.

In the public transport realm, the similarity among routes is more than the "using the same link", it is also "using the same line", "using the same run (time of departure)" and "using the same stations". The fact that the Path Size Logit term is not significant might suggests that the correlation is all in the stations: in the moment we estimate very detailed parameters for the transfers, the similarity is not found any more in the other terms (captured by the Path Size Logit).

The issues of correlation may also be explored further by the recently proposed internally consistent Adaptive Path Size Logit (APSL) model by Duncan et al (2020). Routes contribute here to path size terms according to the ratio of route choice probabilities, ensuring that routes defined as unrealistic by the path size terms, are exactly those with very low choice probabilities. The overlap is thus considered in a more generalized space than the tradition PSL, which may be more suited for the issues of public transport mentioned above. However, it will require further research to transfer the APSL to a schedule-based public transport realm.

For both travel purposes, the transfer waiting time rate of substitution is low; however, waiting time at transfers is always complemented by a transfer penalty, which is equivalent to roughly 8-9 minutes of bus in-vehicle time depending on the purpose of the trip. The low estimate can also to some degree be affected by the highest headway of services in the alternative, since a route with a
high hidden waiting time can suit the passenger well, and possibly make the passenger disregard more frequent alternatives, where the passenger might need to walk further at the access and egress part.

For the in-vehicle time parameters, the different parameters are slightly different from each other. Regional train are normally more comfortable than urban transit. Trips using regional train also in most cases take shorter time compared to busses due to the higher speeds of the regional and intercity trains and this might affect the parameter estimate. However, regional trains had also quite some punctuality problems in the period of the survey, which might explain the higher disutility for in-vehicle time for regional and intercity trains for the leisure related trips. The study by Bovy \& Hoogendoorn-Lanser (2005) also found that the value of access in-vehicle time with transit was lower than the train in-vehicle time between Rotterdam - Dordrecht, Netherlands.

The reason for the very low rate of substitution for the metro in-vehicle time might be explained by metro trips being relatively shorter journeys compared to e.g. regional trains and that the correction for highest frequency in the route does not fully cover the very high frequency of the metro, since trips using only the metro have low hidden waiting times.

Table 5. Estimated parameters and values scaled to bus in-vehicle time for the base models

|  | Work |  | Leisure |  | Rate of substitution <br> (to bus IVT) |  |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: |
| Parameters | Coef. | Rob. t-test | Coef. | Rob. t-test | Work | Leisure |
| In-vehicle time |  |  |  |  |  |  |
| Bus | -0.313 | -20.80 | -0.254 | -22.71 | 1.00 | 1.00 |
| Local train | -0.274 | -9.49 | -0.258 | -9.12 | 0.88 | 1.02 |
| Metro | -0.139 | -6.84 | -0.082 | -4.13 | 0.44 | 0.32 |
| Reg. and intercity train | -0.281 | -12.72 | -0.299 | -10.61 | 0.90 | 1.18 |
| S-train | -0.234 | -15.93 | -0.184 | -14.05 | 0.75 | 0.72 |
| Transfer components |  |  |  |  |  |  |
| Transfer penalty | -2.480 | -18.75 | -2.320 | -19.88 | 7.92 | 9.13 |
| Transfer waiting time | -0.048 | -12.69 | -0.042 | -9.36 | 0.15 | 0.17 |
| Transfer walking time | -0.217 | -8.25 | -0.178 | -7.75 | 0.69 | 0.70 |
| Other components |  |  |  |  |  |  |
| Access time | -0.488 | -18.14 | -0.441 | -23.90 | 1.56 | 1.74 |
| Egress time | -0.418 | -17.53 | -0.364 | -16.57 | 1.34 | 1.43 |
| Half of highest headway in trip | -0.120 | -8.48 | -0.114 | -11.15 | 0.38 | 0.45 |
| No. of est. parameters: | 11 |  | 11 |  |  |  |
| Number of observations: | 2,553 |  | 2,257 |  |  |  |
| Null log-likelihood: | $-12,589$ |  | $-10,765$ |  |  |  |
| Final log-likelihood: | $-2,993$ |  | $-3,489$ |  |  |  |
| Adjusted rho-square: | 0.761 |  | 0.675 |  |  |  |

### 5.2 Model with transfer attributes

Dyrberg \& Christensen (2015) tested several specifications of the different transfer attributes defined in section 2 and found the most suitable representation given significance of the parameters, signs of parameters and overall model. These specifications were further tested for this paper and the
different specifications tested are described below with Table 6 presenting the final MNL estimations for both work and leisure trips. A comparison with the restricted base model using a likelihood-ratio test shows that the model fit is significantly improved for both trip purposes by introducing the transfer attributes to the model, however with the highest degree of impact of the transfer attributes in the model for work related trips.

The parameters capturing ease of wayfinding were tested in four different specifications. Recalling that the ease of wayfinding was assigned a value from easy to difficult for each transfer, it was tested whether ease of wayfinding could be described by just one number: the sum of all the levels encountered (i.e a sum of the levels, when assigning the values 1-4 to the levels), the maximum (worst) transfer or the average of the levels. However, none of these definitions proved useful and thus the method of counting the individual levels of encountered transfers was found to give the best fit. During tests, it proved to be of a high importance to include a general transfer penalty for each transfer encountered, so the different levels of ease of wayfinding were more distinct. The reference level to find differences between the levels was set to "easy". During tests, it was found that there was no significant difference between the "little" and "medium" levels and thus they were combined. The negative parameters for the more difficult ease of wayfinding show that passengers prefer stops and stations with easy wayfinding. However, these parameters are significant only for work related trips, which could be explained by the fact that leisure passengers can be assumed to have less information about the available alternative routes and to have lower value of time, so that the ease of wayfinding does not play a crucial role in the route choices for this group of passengers. For the work related trips, the most difficult transfer stations have a much higher disutility compared to the stations with easier wayfinding. Our empirical results are in line with the hypothesis by Iseki and Taylor (2009) that the level of information has an influence on the perceived walk time.

Similar to the tests of the ease of wayfinding attribute it was tested whether a sum, maximum, average or sum of individual levels gave the best representation of the shopping availability. The tests showed that it did not matter for the passengers which types of shops or how many shops they encountered on the transfers on the route, but only whether at any transfer station there was a shopping possibility. The shopping parameter estimate is not highly significant for work related trips, but the positive estimate shows that passengers prefer routes where transfer stations offer some kind of shopping opportunity, whether this is a kiosk or a larger shop. Since the parameter is less significant for the passenger with a leisure related trip purpose, this indicates that shopping availability does not influence the route choice of leisure passengers because of their assumed lower knowledge of the network, but also that commuters find it attractive to have the opportunity of doing smaller grocery shopping en-route to and from work.

When testing the different specifications of the level changes parameters, only the sum of the escalators encountered at transfer terminals proved to be significant, leaving the model to describe the number of escalators encountered at transfers. Escalators at transfers are preferred by passengers for both trip purposes and the parameter estimate is significant for both purposes. The positive effect of escalator presence is in line with previous findings by Raveau et al. (2011), Guo and Wilson (2011) and Raveau et al. (2014). Escalators reduce the disutility of a trip by about one minute of bus invehicle time. The reason that escalators are experienced positively by the passengers could be explained by the fact that it reduces the effort of walking. Also, since the public transport system in
the Greater Copenhagen Area does not experience excessive crowding, the escalators will in most cases move the passenger faster through the transfer station compared to stairs or long walkways.

The parameters for waiting times at transfers show a clear difference in terms of the significance and the estimates of small and higher waiting times. A total waiting time below 10 minutes is not significant, while the estimate for total waiting time over 10 minutes is significant. The non-significant parameter for low waiting times can be explained by the transfer penalties, which covers the annoyance of having a transfer in the route.

Table 6 also presents the rates of substitution with in-vehicle time by bus as the reference. For the in-vehicle parameters, the change from the base model is small and metro is still the preferred mode when compared to the other sub-modes (everything else being equal). The transfer penalty is still equivalent to roughly 8-10 minutes of bus in-vehicle time for both trip purposes. However, when different transfer attributes are included, a transfer can now be more or less convenient depending on the facilities at the transfer point. The transfer penalties can thus be dissected into several parameters that explain the different preferences for the different transfers, and the transfer penalty can range between 5.4 minutes of bus in-vehicle time for the best transfer (station with easy wayfinding, shopping available and two escalators) to 12.1 minutes for the worst (station with difficult wayfinding and no escalators or shops). Given that the transfer penalties account for up to 12.1 minutes of bus in-vehicle time, this can also be reflected by the insignificance of the small waiting times. It is important to mention, as shown in section 4.2, that very few observations include average waiting times above 10 minutes per transfer and hence these results show that passengers dislike routes with many (long) transfers.

Table 6. Estimated parameter coefficients (robust t-tests) and values scaled to bus in-vehicle time for extended model with transfer attributes

|  | Work |  | Leisure |  | Rate of substitution <br> (to bus IVT) |  |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: |
| Parameters | Coef. | Rob. t-test | Coef. | Rob. t-test | Work | Leisure |
| In-vehicle time |  |  |  |  |  |  |
| Bus | -0.309 | -20.51 | -0.251 | -22.42 | 1.00 | 1.00 |
| Local train | -0.272 | -9.47 | -0.259 | -9.04 | 0.88 | 1.03 |
| Metro | -0.144 | -7.10 | -0.087 | -4.30 | 0.47 | 0.35 |
| Reg. and intercity train | -0.288 | -12.72 | -0.300 | -10.55 | 0.93 | 1.20 |
| S-train | -0.238 | -16.17 | -0.185 | -14.07 | 0.77 | 0.74 |
| Transfer components |  |  |  |  |  |  |
| Transfer penalty | -2.600 | -15.86 | -2.380 | -15.24 | 8.41 | 9.48 |
| Transfer waiting time 0-10 min. | -0.005 | $-0.38^{*}$ | -0.023 | $-1.71^{*}$ | 0.01 | 0.09 |
| Transfer waiting time +10 min. | -0.068 | -8.42 | -0.047 | -6.35 | 0.22 | 0.19 |
| Transfer walking time | -0.219 | -7.67 | -0.193 | -7.81 | 0.71 | 0.77 |
| Shop available at any transfer | 0.176 | $1.32^{*}$ | 0.111 | $0.88^{*}$ | -0.57 | -0.44 |
| Ease of wayfinding - Lit./Mod. | -0.285 | -2.20 | -0.165 | $-1.27^{*}$ | 0.92 | 0.66 |
| Ease of wayfinding - Difficult | -1.130 | -3.70 | -0.127 | $-0.46^{*}$ | 3.66 | 0.51 |
| Escalators at transfer points | 0.384 | 4.83 | 0.267 | 2.89 | -1.24 | -1.06 |
| Other components |  |  |  |  |  |  |
| Access time | -0.484 | -17.95 | -0.440 | -23.87 | 1.57 | 1.75 |


| Egress time | -0.420 | -17.00 | -0.365 | -16.44 | 1.36 | 1.45 |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: |
| Half of highest headway in trip | -0.119 | -8.35 | -0.113 | -11.08 | 0.39 | 0.45 |
| No. of est. parameters: | 16 | 16 |  |  |  |  |
| Number of observations: | 2,553 |  | 2,257 |  |  |  |
| Null log-likelihood: | $-12,589$ | $-10,765$ |  |  |  |  |
| Final log-likelihood: | $-2,965$ | $-3,482$ |  |  |  |  |
| LRT - to base model: | $56.4 \quad(\mathrm{p}=0.00)$ | $13.4 \quad(\mathrm{p}=0.02)$ |  |  |  |  |
| Adjusted rho-square: | 0.763 | 0.675 |  |  |  |  |

*Parameter estimate not significantly different from zero at a $90 \%$ confidence level

### 5.3 Model capturing heterogeneity in passenger preferences

The estimation of an MNL model with the additional transfer variables showed that the different transfers can have a different impact on the transfer penalty perceived by the passengers. A Mixed Logit model was estimated based on the final MNL model to investigate possible heterogeneity in how passengers perceive the penalties. Initial models were run with only one parameter mixed at a time in order to assess whether a parameter should be included as a distributed parameter, and a final model was estimated where all parameters with a significant distribution were included until all the distributed parameters left in the model were significant. All time-related variables and the general transfer penalty were tested with log-normal distributions, while for the additional transfer variables it was tested if either log-normally or normally distributed parameters led to the best model fit. It turned out that all significant variables were perceived with heterogeneity better represented by positive log-normal distributions than normal distributions.

Table 7 shows the final Mixed Logit models for work related trips while Table 8 shows the final model for leisure related trips, where likelihood-ratio tests show that the added mixed variables significantly improves the model fit compared to the MNL model with transfer related variables. The model converged nicely, and the resulting rate of substitutions were reasonable showing, that the lognormal distributions did not have unreasonable thick long tail, and hence suggests that most passengers have indeed reasonable preferences.

The in-vehicle time related variables only have significant distributions for some of these and it differs between the trip purposes, with only the parameter for in-vehicle time for regional train distributed for both purposes. The access and egress parameters have significant distributions for both purposes with similar standard deviations for both access and egress.

The general transfer penalty has a significant distribution with high standard deviation especially for the leisure trips, meaning leisure passengers perceive the penalty of transferring quite differently. The waiting and walking times did not show any significant distribution parameter for either trip purpose. Regarding the transfer attributes only the parameters for shopping availability for work related trips and number of escalators for leisure related trips proved to have significant distributions. The shopping availability for work related trips has a significant distribution, while the mean of the distribution is not highly significant. The ease of wayfinding is still insignificant in the model for leisure related trips, while they are significant in the model for work related trips and with an even larger disutility for stations with very difficult wayfinding.

With the aim of comparing the rates of substitution for different parameters with respect to the bus in-vehicle time, Monte Carlo simulations with 1 million draws from the distributions were performed and $95 \%$ confidence levels were calculated as shown in Table 7 and 8. The rate of substitution between the different in-vehicle time parameters are in general within expectations and the intervals are in general largest in the model for leisure related trips time and reflects that especially these passengers do have different preferences for the different sub-modes. The confidence intervals for access and egress rate of substitution is in general higher than the rate of substitution in the MNL model, but still with access being the most critical part of the access and egress to stops. The hidden waiting time is highly distributed leading to a large span in the rate of substitutions, with some passengers finding the possibility of departing frequently very important.

The rate of substitution for the transfer penalty is between 3.5 and 29.6 minutes of bus invehicle time, with a higher standard deviation for leisure passengers compared to passengers travelling for work related trip purposes. This suggests that the leisure passengers are quite a heterogeneous group of passengers, with possibly heterogeneous spatial patterns and time constraints throughout the day. The importance of walking time at transfers is now closer to bus in-vehicle time, while the importance of waiting time is still suppressed by the transfer penalties covering the annoyance of transferring. The distribution for shopping available at transfers for work related trips show that this is equal to 0.1 to 3.2 minutes of bus in-vehicle time while approximately the same range is the case for escalators at transfer for leisure related trips.

Table 7 - Mixed Logit estimates, means and standard deviation for the log-normal distribution, rates of substitution (w.r.t. bus in-vehicle time) and [ $95 \%$ confidence intervals] - work related trips

|  | Work |  | Parameters in equivalent normal |  | Rate of substitution (to bus IVT) |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Parameters | Coef. | Rob. $t$ test | Mean | Std. dev | Mean | 95\% confidence interval |
| In-vehicle time |  |  |  |  |  |  |
| Bus ( $\mu$ ) | -0.711 | -9.19 | -(0.51) |  | 1.00 | [1.00-1.00] |
| Bus ( $\sigma$ ) | 0.307 | 5.91 |  | 0.16 |  |  |
| Local train | -0.399 | -7.70 |  |  | 0.85 | [0.44-1.48] |
| Metro | -0.198 | -6.08 |  |  | 0.42 | [0.22-0.74] |
| Reg. and intercity train ( $\mu$ ) | -0.945 | -9.55 | -(0.41) |  | 0.88 | [0.33-1.91] |
| Reg. and intercity train ( $\sigma$ ) | 0.329 | 4.44 |  | 0.14 |  |  |
| S-train | -0.355 | -12.64 |  |  | 0.76 | [0.40-1.32] |
| Transfer components |  |  |  |  |  |  |
| Transfer penalty ( $\mu$ ) | 1.430 | 15.40 | -(4.42) |  | 9.44 | [3.49-20.74] |
| Transfer penalty ( $\sigma$ ) | 0.335 | 5.56 |  | 1.52 |  |  |
| Transfer waiting time 0-10 min. | -0.008 | -0.38* |  |  | 0.02 | [0.01-0.03] |
| Transfer waiting time +10 min . | -0.109 | -6.30 |  |  | 0.23 | [0.12-0.41] |
| Transfer walking time | -0.387 | -8.20 |  |  | 0.83 | [0.43-1.44] |
| Shop available at any transfer ( $\mu$ ) | -1.580 | -1.44* | 0.33 |  | -0.71 | [-3.16-(-0.06)] |
| Shop available at any transfer ( $\sigma$ ) | 0.984 | 2.98 |  | 0.43 |  |  |
| Ease of wayfinding - Lit./Mod. | -0.377 | -1.98 |  |  | 0.8 | [0.42-1.40] |
| Ease of wayfinding - Difficult | -1.840 | -3.76 |  |  | 3.93 | [2.05-6.85] |
| Escalators at transfer points | 0.591 | 4.33 |  |  | -1.26 | [-2.20-(-0.66)] |
| Other components |  |  |  |  |  |  |
| Access ( $\mu$ ) | -0.149 | -2.05 | -(0.93) |  | 1.99 | [0.66-4.66] |
| Access ( $\sigma$ ) | 0.392 | 7.27 |  | 0.38 |  |  |
| Egress ( $\mu$ ) | -0.276 | -3.48 | -(0.82) |  | 1.75 | [0.58-4.10] |
| Egress ( $\sigma$ ) | 0.390 | 7.39 |  | 0.33 |  |  |
| Half of highest headway in trip ( $\mu$ ) | -1.450 | -12.70 | -(0.71) |  | 1.52 | [0.02-9.48] |
| Half of highest headway in trip ( $\sigma$ ) | 1.490 | 42.63 |  | 2.04 |  |  |
| No. of est. parameters: | 23 |  |  |  |  |  |
| Number of observations: | 2,553 |  |  |  |  |  |
| Null log-likelihood: | -12,589 |  |  |  |  |  |
| Final log-likelihood: | -2,596 |  |  |  |  |  |
| LRT - to transfer model: | 737.5 | $(\mathrm{p}=0.00)$ |  |  |  |  |
| Adjusted rho-square: | 0.792 |  |  |  |  |  |

*Parameter estimate not significantly different from zero at a $90 \%$ confidence level
-() for means indicate negative log-normal distributions. Estimate for shop availability at any transfer is the only positive log-normal distribution.

Table 8 - Mixed Logit estimates, means and standard deviation for the log-normal distribution, rates of substitution (w.r.t. bus in-vehicle time) and [ $95 \%$ confidence intervals] - leisure related trips

|  | Leisure |  | Parameters in equivalent normal |  | Rate of substitution (to bus IVT) |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Parameters | Coef. | Rob. $t$ test | Mean | Std. dev | Mean | 95\% confidence interval |
| In-vehicle time |  |  |  |  |  |  |
| Bus | -0.412 | -14.31 |  |  | 1.00 | [1.00-1.00] |
| Local train | -0.236 | -5.27 |  |  | 0.57 | [0.57-0.57] |
| Metro ( $\mu$ ) | -3.600 | -4.65 | -(0.25) |  | 0.60 | [0.00-4.04] |
| Metro ( $\sigma$ ) | 2.100 | 5.38 |  | 2.23 |  |  |
| Reg. and intercity train ( $\mu$ ) | -0.944 | -8.44 | -(0.49) |  | 1.18 | [0.25-3.53] |
| Reg. and intercity train ( $\sigma$ ) | 0.674 | 6.19 |  | 0.37 |  |  |
| S-train ( $\mu$ ) | -1.590 | -12.89 | -(0.27) |  | 0.67 | [0.11-2.23] |
| S-train ( $\sigma$ ) | 0.768 | 12.56 |  | 0.25 |  |  |
| Transfer components |  |  |  |  |  |  |
| Transfer penalty ( $\mu$ ) | 1.540 | 12.64 | -(5.26) |  | 12.76 | [4.33-29.57] |
| Transfer penalty ( $\sigma$ ) | 0.490 | 2.66 |  | 2.74 |  |  |
| Transfer waiting time 0-10 min. | -0.024 | -1.10* |  |  | 0.06 | [0.06-0.06] |
| Transfer waiting time +10 min . | -0.096 | -5.86 |  |  | 0.23 | [0.23-0.23] |
| Transfer walking time | -0.400 | -7.57 |  |  | 0.97 | [0.97-0.97] |
| Shop available at any transfer | 0.490 | 1.97 |  |  | -1.19 | [-1.19-(-1.19)] |
| Ease of wayfinding - Lit./Mod. | -0.337 | -1.51* |  |  | 0.82 | [0.82-0.82] |
| Ease of wayfinding - Difficult | 0.127 | 0.27* |  |  | -0.31 | [-0.31-(-0.31)] |
| Escalators at transfer points ( $\mu$ ) | -0.700 | -1.95 | 0.57 |  | -1.39 | [-3.43-(-0.42)] |
| Escalators at transfer points ( $\sigma$ ) | 0.533 | 3.03 |  | 0.33 |  |  |
| Other components |  |  |  |  |  |  |
| Access ( $\mu$ ) | -0.138 | -1.60* | -(1.00) |  | 2.42 | [0.76-5.89] |
| Access ( $\sigma$ ) | 0.523 | 3.84 |  | 0.56 |  |  |
| Egress ( $\mu$ ) | -0.278 | -3.56 | -(2.05) |  | 2.11 | [0.65-5.15] |
| Egress ( $\sigma$ ) | 0.526 | 12.02 |  | 0.49 |  |  |
| Half of highest headway in trip ( $\mu$ ) | -1.410 | -13.11 | -(0.40) |  | 0.98 | [0.08-4.2] |
| Half of highest headway in trip ( $\sigma$ ) | 1.000 | 10.92 |  | 0.53 |  |  |
| No. of est. parameters: | 24 |  |  |  |  |  |
| Number of observations: | 2,257 |  |  |  |  |  |
| Null log-likelihood: | -12,589 |  |  |  |  |  |
| Final log-likelihood: | -3,017 |  |  |  |  |  |
| LRT - to transfer model: | 929.6 | ( $\mathrm{p}=0.00$ ) |  |  |  |  |
| Adjusted rho-square: | 0.717 |  |  |  |  |  |

*Parameter estimate not significantly different from zero at a $90 \%$ confidence level
-() for means indicate negative log-normal distributions. Estimate for escalators at transfer points is the only positive log-normal distribution.

## 6 DISCUSSION AND CONCLUSIONS

This study has analysed how passengers consider attributes for transfers in multimodal public transport network, such as ease of wayfinding, presence of shops and escalators. We proposed different ways of defining and measuring these variables, and based on initial testing in Dyrberg \& Christensen (2015) and further model tests, concluded on the variable definitions. We then presented route choice models for the large-scale multimodal public transport network in the Greater Copenhagen Region, where these transfer attributes were included in a unified model framework. The models were estimated on an extensive dataset of 4,810 observed routes. We believe that this is the first time that such an extensive dataset of observed routes has been used to estimate a multimodal public route choice model in a metropolitan setting that includes a variety of transfer related attributes that can be used for explanatory as well as predictive purposes.

The main overall conclusion is that it was possible to disentangle transfer penalties and values of time for transfers into the sub-components mentioned above, and to significantly estimate different parameters for this. In the specific case, this was used to improve the route choice modelling of passengers in the Greater Copenhagen Region and hence to make it possible to analyse policies to improve public transport terminals. While studies in the literature have provided ranges of fixed transfer penalties from 5 to 20 minutes for different cases, this paper disentangled the value for one transfer, ranging from 5.4 minutes for the best possible transfer to 12.1 minutes for the worst possible transfer. These variables can directly be implemented and used in a route choice model, and subsequently used for policy evaluations, i.e. predicting the impact on route choice and generalised level of service if a given terminal is improved.

Although it is difficult to compare the impedance of individual parameters defining the route choice preferences across studies, the range of the values for transfer related parameters in this study are in line with fixed values of transfer penalties and values of walking and waiting times in other studies. We therefore propose that they can be a guideline for more studies to disentangle transfer penalties in other cities, as the specific values and ratios between parameters may depend on the case context. The two additional transfer variables included in this study, namely presence of shops and escalators at transfer points are easily measurable and more detailed data can be applied if for example the distance to shops at transfers is available in other datasets. Ease of wayfinding was defined as described in section 2.1 and further elaborated in Dyrberg \& Christensen (2015). Further research might quantify this into a set of detailed measurable variables along the path within the terminal describing the transfer. This would however need much more detail on the lay out of the terminals than available for the present study.

Although different weather conditions and other conditions in different countries can affect the magnitude of the impact on passengers' route choices, we expect that the measures are transferable to other cities in the world. The variables on shelters were not significant in the study. This was probably because all major terminals have shelters in the Copenhagen Region, and data thus had little variation, whereas bus to bus transfers which are the only ones with non-shelter conditions are correlated to the higher disutility of bus compared to rail.

The large heterogeneity found in the preferences of different transfer attributes suggest that there might be other factors, which influence the transfer penalty. This could for example be different socio-economic factors, which influence the perceived importance of shopping availability or the comfort of having escalators at stations. The heterogeneity also indicates that further research is needed to refine the definition of the attributes and to explain the differences in passengers' route choice preferences. An interesting line of research to explain more on transfer related variables could be including waiting time and boarding strategies at transfer stations (see for example Nassir et al. (2019) or Schmöcker et al. (2013). Analysing the problem using a sequential choice strategy could possibly allow for more detailed descriptions of the choice of different transfer stations.

Most politicians are focused on investments that improve the level of service of public transport operations, for example travel time savings or increase of frequencies, which require massive investments in infrastructure and rolling stocks, and which often only improve travel times or waiting times with few minutes. The study presented here suggests that improved transfers may be perceived by passengers to be of at least the same order of magnitude as such projects, whereas they are often much cheaper in terms of investments. We therefore recommend that more detailed route choice models and analyses are used when prioritising among investments in public transport.

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