The influence of vicinity to stations, station characteristics and perceived safety on public transport mode choice

a case study from Copenhagen

Ingvardson, Jesper Bláfoss; Nielsen, Otto Anker

Published in:
Public Transport

Link to article, DOI:
10.1007/s12469-021-00285-x

Publication date:
2022

Document Version
Peer reviewed version

Citation (APA):
Ingvardson, J. B., & Nielsen, O. A. (2022). The influence of vicinity to stations, station characteristics and perceived safety on public transport mode choice: a case study from Copenhagen. *Public Transport*, *14*, 459-480. https://doi.org/10.1007/s12469-021-00285-x

Public Transport
https://doi.org/10.1007/s12469-021-00285-x

CASE STUDY AND APPLICATIONS

The influence of vicinity to stations, station characteristics and perceived safety on public transport mode choice: a case study from Copenhagen

Jesper Bláfoss Ingvardson[1] · Otto Anker Nielsen[1]

Accepted: 12 September 2021

Abstract

The perception of safety within the public transport system is of high importance for passengers according to multiple passenger satisfaction surveys. However, among the many studies of public transport mode choice, little focus has been on the influence of safety perceptions. This study contributes to existing literature by specifically investigating the influence of perceived safety on public transport mode choice using a large-scale multimodal travel survey with 17,355 respondents and 42,438 trips from the Greater Copenhagen area. This made it possible to analyse safety at stations while still taking into account other main determinants of public transport usage. The study also includes walking distances to various public transport stops, e.g. metro, suburban and regional train stations, and bus stops, hence taking into account possible differences in attitudes towards different public transport modes. The results of a logistic regression confirm the hypothesis of lower perceived safety at stations being negatively correlated with public transport mode choice, but still to a smaller extent than that of service characteristics in terms of service frequency. The study also revealed that travellers perceive metro and suburban rail services as more attractive, as compared to local rail and bus services. Hence, vicinity to such stations was associated with a higher likelihood of choosing public transport, thus highlighting the importance of close vicinity to high-class services being of the highest importance for attracting passengers to public transport while perceived safety being of minor, yet significant, importance.

Keywords Public transport ridership · Perceived safety · Travel survey · Mode choice · Station vicinity

✉ Jesper Bláfoss Ingvardson
jbin@dtu.dk

Otto Anker Nielsen
oani@dtu.dk

[1] Transport Division, Department of Technology, Management and Economics, Technical University of Denmark, Bygningstorvet 116B, 2800 Kgs. Lyngby, Denmark

Published online: 06 October 2021

1 Introduction

Perceptions of personal safety have been highlighted as being of major importance for passengers in the public transport system. Results from a UK study suggested that 10% would reconsider using public transport if their fears were addressed (Crime Concern 2004), and in Denmark, only 77% of the passengers reported to be satisfied with the safety in the public transport system according to a recent satisfaction survey (Passagerpulsen 2017). Furthermore, perceived safety and security have been reported as an essential parameter across multiple other passenger satisfaction studies (Stuart et al. 2007; Fellesson and Friman 2012; Spears et al. 2013; Iseki and Taylor 2015), together with the traditional service level elements, e.g. service coverage, frequency, and travel speed (Eboli and Mazzulla 2015; Mouwen 2015; Imaz et al. 2015; Eboli et al. 2018a; van Lierop et al. 2018).

While no direct correlation between reported crime levels at and around stations and fear of crime has been identified, a potential fear might influence travellers' choice of using public transport. Despite this, only few studies have explicitly analysed the influence of perceived safety on travel behaviour in general and on public transport ridership in particular. Kim et al. (2007) analysed factors influencing mode choice between home and light rail stations, i.e. access/egress trip legs, and found that crime had a significant impact on mode choice as female transit riders were more likely to be dropped off and picked up at the station instead of walking. In Börjesson (2012) the influence of perceived safety on the valuation of walking time was analysed. This study found that walking in closed environments was associated with higher disutility for both women and men during night hours suggesting an effect of perceived safety. Only Delbosc and Currie (2012) have analysed explicitly the influence of safety perceptions on public transport usage finding a significant impact on public transport use frequency. However, a main limitation of this study was the use of a small convenience sample of only 784 respondents, which was not representative of the general population (Delbosc and Currie 2012).

These studies suggest the influence of perceived safety as a contributing determinant of travel behaviour, but they, however, have shortcomings in terms of analysing its significance on actual public transport ridership. This study fills the gap in research by analysing on a larger scale the influence of perceived safety on public transport mode choice in the Greater Copenhagen area. The contribution is two-fold.

First, the study analyses the actual influence of perceived safety at the station-level for each trip undertaken by travellers. This allows for estimating the effect on mode choice, thereby determining the actual effect on ridership in the public transport system. Furthermore, important characteristics influencing the perceived safety level, e.g. station characteristics in terms of availability of shops, and the time-of-travel, could be included as these characteristics might also influence the perceived safety level.

Second, the study considers a wide range of service and socio-demographic characteristics related to the individual trip, which made it possible to control for important trip and traveller characteristics highlighted as important determinants of ridership by previous research (Taylor and Fink 2013). This also includes the influence of vicinity to public transport stops served by different public transport modes, hence enabling an analysis of the influence of modes with varying attractiveness and service frequency. This is achieved by deploying a large-scale dataset based on the Danish National Travel Survey (Christiansen 2015), which holds a vast amount of information about the respondents, including socio-economic background information. The utilisation of the travel survey data ensures a large representative sample of the general population as approximately 10,000 responses are collected every year.

The remainder of the paper is structured as follows. Section 2 reviews the literature on the determinants of public transport ridership. In Sect. 3, the study area is briefly presented including description of the data sources used for the model estimations. The results are presented and discussed in Sect. 4. Section 5 concludes the work by pointing to relevant policy implications.

2 Determinants of public transport ridership

Many previous studies have investigated the factors affecting public transport satisfaction, passenger loyalty and ridership focusing on the influences of land uses, the built environment and characteristics related to the public transport system and the travellers. As the focus of this paper is on ridership effects, less emphasis will be on travel satisfaction and loyalty; however, an extensive review can be found in van Lierop et al. (2018). For ridership effects an extensive review can be found in Ingvardson and Nielsen (2018). Most of these ridership studies range from analysing station-level ridership over line- or corridor-level ridership to full network ridership, with only few studies analysing individual mode choice, and even fewer considering perceived safety. This section focuses on recent studies involving perceived safety as well as traditional socio-economics, land use and service quality variables; hence, highlighting the important characteristics to be included in the subsequent analyses.

2.1 Safety and security

The importance of safety and security has been analysed thoroughly with regards to the influence on travel satisfaction and loyalty in the public transport system, e.g. van Lierop et al. (2018). However, only limited research has focused on the influence on actual public transport usage despite it being highly relevant as fear of crime can restrain travellers from using public transport (Abdul Hamid et al. 2015). Specifically, Badiora and Okunola (2015) suggested that fear of crime is a stronger influential factor against public transport usage than actual crime levels. Furthermore, according to a British study ridership increases were suggested to be up to 10% when travellers feel safe at stations (Cozens and van der Linde 2015). Hence, proper transport planning should ensure safe, secure and comfortable public transport environments (Ceccato 2014; Cozens and van der Linde 2015). To the knowledge of the authors, only a single study quantified the actual effect of safety perceptions on public transport usage (Delbosc and Currie 2012). Based on 784 respondents of a household interview survey, the study found a general positive relationship between public transport usage and feeling safe within the public transport system, and the effect was only slightly smaller than the negative effect of car ownership. In addition, safety perceptions were significantly related to the female gender and increased age, hence suggesting lower usage among women and elderly persons. This is in line with results from several other studies agreeing that the perception of personal security is more important for female passengers than for men (Kim et al. 2007; Fan et al. 2016). Specifically, Lynch and Atkins (1988) found an increased unease among women travelling with public transport at night times, and findings suggested that low perceived safety influenced the travel behaviour of women, e.g. by not travelling at all. Therefore, particular attention must be paid to the needs and desires of women in both design and management of stations (Şimşekoğlu et al. 2015; van Lierop and El-Geneidy 2016). Specifically, stations should have proper route and schedule information (Iseki and Taylor 2015), as well as good lighting, vigilant guards and a clear station design as the layout of stations can positively influence passengers' safety perceptions (Abdul Hamid et al. 2015). Finally, Masoumi and Fastenmeier (2016) reviewed the literature finding that the use of modern technology, e.g. surveillance cameras, increased the perception of safety.

2.2 Socio-economic characteristics

Much research has analysed the influence of various socio-economic characteristics on public transport ridership. Several studies found that women generally use public transport more often than men (Limtanakool et al. 2006; Beirão and Sarsfield Cabral 2007). In the Netherlands, this was suggested to be due to public transport being less stressful than driving a car. In Smith (2008), it was suggested that women and children need to feel safe and secure at stations to use public transport more extensively. However, among residents in Calgary, Canada, it was found that men use public transport more than women and children (Pasha et al. 2016).

Similarly, inconsistent results regarding the influence of age on public transport usage have been identified in the literature. In Sweden and Denver (Colorado) it was found that seniors make fewer and shorter trips (Boschmann and Brady 2013; Heikkinen and Henriksson 2013). In Hjorthol (2013), this is suggested to be due to seniors facing more difficulties travelling by public transport than walking or driving. On the other hand, Limtanakool et al. (2006) found that in the United States people start using public transport more for medium and long-distance trips as they get older.

Many studies found a negative income effect suggesting lower ridership among higher-income travellers. Some studies even found income to be the most influential factor (Chakraborty and Mishra 2013; Levinson and Zhu 2013). This can be attributed to a positive correlation between higher-income people and car ownership rates, which results in lower public transport usage (Paulley et al. 2006). Specifically, car ownership has been reported as being significantly negatively correlated with public transport usage, potentially with larger impacts than the characteristics of the public transport system itself (Taylor and Fink 2013). Similarly, lower income and unemployment rates are positively correlated with transit ridership (Pasha et al. 2016; Barton and Gibbons 2017). However, inconsistent findings concerning unemployment rates have been reported by other studies where positive effects on ridership can be observed, e.g. due to the financial crisis in Spain that resulted in increased bus usage (Cordera et al. 2015). On the other hand, negative effects on ridership were seen in several other studies, possibly due to reduced travel frequency. Ownership and use of bicycles have been found to be positively related to public transport usage, possibly because bicycles can be used in conjunction with public transport, e.g. as feeder mode to rail stations. Therefore, Chen and Zhao (2013) suggest adding more bicycle parking spaces at transit stations, thus enabling travellers to use bicycles for their last mile of travel.

2.3 Land use and built environment

Ridership and proximity to transit stations are significantly positively correlated (Chen and Zhao 2013; Liu et al. 2016). Hence, high population and employment densities around transit stations ensure a larger share of travellers in close proximity to stations thus resulting in a greater use of public transport (Gutiérrez et al. 2011; Chakraborty and Mishra 2013). Specifically, Ewing and Cervero (2010) suggested an 2.66% increase in ridership if population density increased by 10% around transit stations, hence highlighting the importance of dense urban areas in connection with public transport. Other studies reported a significant positive influence from more parking spaces around stations as well as mixed land use areas (Pasha et al. 2016).

2.4 Service quality

Many studies have analysed experienced service quality and specifically the relationship between various service quality elements and characteristics of the public transport system on one hand, and passenger satisfaction, user loyalty and ridership on the other hand (De Oña et al. 2013; Guirao et al. 2016; van Lierop and El-Geneidy 2016; van Lierop et al. 2018). While findings vary across studies, most emphasise the importance of *reliability* (Cantwell et al. 2009; Eboli and Mazzulla 2015; Imaz et al. 2015), *travel time* (Imaz et al. 2015; Abenoza et al. 2017), *comfort* (Cantwell et al. 2009; Imaz et al. 2015), and *information* (Eboli and Mazzulla 2015; Abenoza et al. 2017). An important note is that the service needs to be accessible to the users, as public transport usage declines with increasing distance to the system (Buehler 2011). Hence, an important parameter for users is the distance to the actual public transport services, and thus the perceived service quality has a spatial dimension identified by several studies. Eboli et al. (2018b) analysed perceived service quality at Italian train stations and found a significant spatial autocorrelation among responses, and Nkurunziza et al. (2012) found that stated preference for a proposed public transport service was strongly linked to geographical areas of Dar es Salaam, Tanzania.

Previous studies on ridership determinants have used various objective indicators for service quality, including the service frequency (e.g. Chiou et al. 2015; Taylor et al. 2009) and number of lines serving the station (e.g. Jun et al. 2015; Zhao et al. 2013; Derrible and Kennedy 2009). However, many studies have also highlighted the availability of various service and station characteristics to be positively related to ridership (Guo and Wilson 2011). This included provision of real-time information at bus stops (Dziekan and Kottenhoff 2007), integrated ticketing (Crampton 2002; Currie et al. 2011), availability of bicycle amenities (Blainey and Mulley 2013; Zhao et al. 2013), and park-and-ride facilities for car users (Kuby et al. 2004; Cervero et al. 2010; Guerra et al. 2012). In terms of station amenities, it has also been suggested that the presence of medical, financial, shopping and food services will increase ridership while education and recreation-related services will decrease transit ridership (Hong et al. 2017). In Dyrberg and Christensen (2015), it was concluded that passengers' route choice was negatively affected by simple station layouts, the availability of shelters and shops at stations, hence suggesting the importance of station amenities and simple layouts to attract passengers. Hence, these findings suggest that many characteristics influence travellers' choice of public transport, e.g. both characteristics related to the service, but also station characteristics, including the spatial dimension in terms of vicinity to the nearest station, thus highlighting the importance of including a broad range of indicators in the subsequent analysis.

3 Data and methods

3.1 Travel survey data

This study mainly deployed data from the Danish National Travel Survey (TU) collected from the Greater Copenhagen area (Christiansen 2015). The data is a travel diary covering all trips performed by the respondent during the interview day. As 10–12,000 respondents are interviewed every year, the dataset used for this study covering the Greater Copenhagen area in the period 2009–2018 included a total of 105,268 trips.

This data also holds a vast amount of background information about the respondents, including socio-economic characteristics (e.g. gender, age, household and respondents' income, education level, job type) and travel-related characteristics (e.g. car availability, driver's license, bicycle ownership, distance to nearest station). The detailed information makes it possible to include many relevant parameters in the model estimation, thereby allowing to control the relevant determinants of mode choice as identified in the literature review in Sect. 2.

3.2 Station characteristics

The dataset was linked to characteristics related to every station in the study area. This included the perceived safety level experienced by passengers. The main variable was the result of a passenger survey that ranked the perceived safety at each station using a 10-point Likert scale. The state railway company, DSB, performed the survey every year in the period 2009–2015 for all DSB S-train and regional train stations. From 2016 and onwards the survey has been continued by Passagerpulsen, a national body representing the passengers' interests with regards to public transport. Hence, data for 2016–2018 were also included in this study. For all years included in the study, the average number of respondents per station was 100–300 ensuring sufficiently the reliability of the perceived safety level. However, the data only cover S-train and regional train stations, i.e. no data were available for the Copenhagen metro and the small local railway stations. Considering that the S-train and regional train stations cover approximately half of the rail passengers in the Greater Copenhagen area this was acceptable. However, based on this, it was decided to perform the final model estimations in a two-fold manner, namely (i) using all data, but without the perceived safety data, and (ii) using a subset of data that included the perceived safety data.

For all stations several other characteristics were collected. This included the availability of shops as this was hypothesised to be related to the perceived safety level as stations might be perceived as more attractive when shops are available due to staff being present at the shop. Also, information about the availability of shelters, i.e. small or large shelters, and whether the station is located underground was collected. Finally, the ease of wayfinding at the station was included as this might have an effect on whether passengers perceive stations as attractive. These data were collected from Dyrberg and Christensen (2015) for all stations, and thus included in the model estimations.

3.3 Service quality

The perceived attractiveness of the public transport system was incorporated in a three-fold manner for each trip based on the findings of the literature in Sect. 2. Hence, this included (i) spatial vicinity to stations and stops, (ii) the service frequency at the nearest bus stops and train stations, and (iii) travel times by car and public transport for the specific trip, thus representing the competition to the main alternative mode.

The vicinity to the public transport network was obtained through spatial analyses, which included analysing the street network distance from the origin and destination of each trip leg to the nearest public transport stops of all modes using a detailed network of streets and smaller pedestrian paths. For each origin and destination, the exact coordinates were obtained from the travel survey data; however, due to privacy issues, the output used in this study was the distance in 200 m intervals. The maximum search distance was set at 2000 m. The analysis included all relevant rail lines and bus lines. Due to the many service types in the Greater Copenhagen area they were categorised based on type and service frequency. Train stations were categorised in four categories, namely (i) metro, which connects 22 stations mainly located in the city centre and towards Copenhagen Airport at a very high service frequency throughout the day (2–6 min headways), (ii) suburban rail (S-train), which connects the city centre to the suburbs totalling 85 stations (5–10 min headways), (iii) regional/long-distance rail, which only serves the main stations, but offer fast travel speeds over long distances (20–60 min headways), and (iv) local rail, which runs infrequently in a few suburbs at low speeds (30–60 min headways). Bus stops were categorised in three categories due to the bus network in Copenhagen incorporating S-bus lines (frequent and fast buses with longer distances between stops), A-bus lines (frequent buses with shorter stop distances), and regular buses (less frequent buses with many stops, and often local detours). By calculating the distance to the nearest station/stop serviced by each of the seven public transport services, it allowed for incorporating possible differences in perceptions of the various public transport modes.

The service frequency was collected for the nearest rail and bus stops. For the nearest rail station, the hourly service frequency of a typical weekday was included. However, as timetables for buses change more frequently than those for trains (which were constant over several years in Copenhagen), it was not possible to collect specific hourly departures for bus stops across years. Instead, the number of daily departures gathered for a representative weekday of each year, i.e. the first Thursday in March, was used for bus stops. This was included for the nearest bus stop serviced by A-, S- and regular buses, respectively. Despite not being an accurate service frequency for each individual trip, it was regarded as a representative indicator for the general service level and hence attractiveness of the nearest bus stop. Hence, this was not expected to cause notable bias in the model estimations. On the contrary, it enabled detailed public transport characteristics in the subsequent model estimations.

Finally, travel times for car and public transport were calculated based on the origin and destination for each trip. These were taken from the Danish National Transport Model (NTM) and included the total travel times, i.e. for cars this included the travel time with congestion effects, whereas for public transport it included in-vehicle travel time, access- and egress times, and walking and waiting times at transfers. This allowed for calculating the ratio between the travel times by car and public transport, respectively, which ensured that the model estimation also included the relative attractiveness of public transport as compared to the main alternative mode, car.

3.4 Sample statistics

The full travel survey dataset included 102,813 trips performed by 32,229 respondents in the Greater Copenhagen area during 2009–2018. This area covers the commuting area of the city of Copenhagen, which has a population of approximately 1.2 million.

For the subsequent analyses three important constraints were made on the data. First, station characteristics were linked to the station located nearest to the origin of the trip, but it was required that the station was located within 2000 m from the trip origin. This was chosen due to the assumption of station characteristics not being important if the station is located far from the trip origin. Second, short trips of less than 2000 m were excluded from the dataset. This was done to better analyse the importance of public transport service characteristics on mode choice. For trips shorter than 2000 m the walking and bicycling mode shares are 33.7% and 29.6%, respectively, whereas public transport is a mere 2.8%, probably due to access and egress times being relatively long for such short trips. The threshold was set at 2000 m due to the large amount of bicyclists in the Copenhagen area, but in other settings where bicycles are not as widely used, it could be considered to lower this threshold. Third, approximately 25% of the observations did not include income information on the traveller. Since this parameter usually has a large influence on transport mode choice it was decided to estimate the models on the subset of observations for which income was available. It was considered to impute the income variable using advanced techniques, e.g. multiple imputation or hot-deck imputation (Andridge and Little 2010); however, this was disregarded because the variables that could be used to predict the missing income information would also be needed in the estimation of public transport mode choice. These assumptions resulted in a dataset of 42,438 trips performed by 17,355 respondents to be used in the subsequent model estimations.

The summary statistics of the data used on the model estimations as well as those of the full dataset are shown in Table 1. It shows that the survey characteristics correspond well to the general population of the Greater Copenhagen area, which is not surprising as the survey is collected as a representative sample. However, there are discrepancies, mainly due to the three restrictions put on the data.

The mode share of public transport for trips longer than 2000 m in the Greater Copenhagen area is around 17%, with larger shares in the inner city areas where the public transport network is more dense and frequent. It can also be seen that bicycling constitutes a relatively large mode share of almost 24% of all trips in the region, and 17.5% of non-short trips. This is mainly due to its even larger share of around one third of trips in the city of Copenhagen (Christiansen 2015). Walking trips have a large share for very short trips.

3.5 The link between average household income and perceived safety

It has been hypothesised in previous US studies that perceived safety (and crime levels) are related to average household income in a given area (Kim et al. 2007; Loukaitou-Sideris 2014; Iseki and Taylor 2015). However, other studies argue that the actual crime level is not an adequate indicator for perceived safety and security (Badiora et al. 2015). For the Greater Copenhagen area, a significantly positive relationship was observed between the perceived safety at stations and the average income of households in the station vicinity area of that given station, cf. Fig. 1, which shows the relationship between the perceived safety score at stations and the average household income in the station vicinity are, i.e. within 1000 m of the station, across the years 2009–2018. Hence, this suggests

Table 1 Summary statistics for the dataset of trips from the Danish national travel survey (TU) used in this study, compared to statistics for the full TU dataset including observations with missing values, and to official figures from the study area based on Statistics Denmark

	[%] (N = 17,355)	Full TU sample (N = 32,229)	Statistics Denmark (%)
Gender			
Male	52.3	49.5	49.3
Female	47.7	50.5	50.7
Age			
0–15	5.8	8.3	16.6
16–25	13.8	15.4	12.4
26–45	39.3	35.5	26.5
46–67	33.6	30.4	31.3
> 67	7.5	10.4	13.3
Car ownership			
Yes	73.0	70.8	54.0
No	27.0	29.2	46.0
Driver's license			
Yes	82.4	75.0	–
No	17.6	25.0	–
Bicycle ownership			
Yes	78.4	77.0	–
No	21.6	23.0	–
Education level			
High-school	11.9	12.2	10.8
Tertiary	22.2	21.6	31.7
Bachelor	27.7	25.6	17.2
Graduate	21.7	18.4	13.4
Other	16.6	22.2	26.9
Employment status			
Employed	61.1	51.8	58.8
Student	9.2	8.7	16.3
Retired	8.9	12.4	–
Unemployed	2.4	3.4	2.5
Other	18.4	23.8	22.4
Annual household income (1000 Euros)			
0–33	21.7	–	28.7
33–66	29.7	–	34.1
66–100	28.4	–	15.4
100–133	12.8	–	10.4
> 133	7.5	–	11.5
Trip distance (km)			
2–4.9	38.6	36.5	–
5–9.9	25.4	26.0	–
10–19.9	20.9	21.6	–
20–29.9	8.4	8.8	–
> 30	6.7	7.1	–

Table 1 (continued)

	[%] (N = 17,355)	Full TU sample (N = 32,229)	Statistics Denmark (%)
Mode choice (all)			
Public transport	10.2	11.2	–
Car	47.3	47.0	–
Bike	23.9	23.2	–
Walk	16.4	16.5	–
Other	2.2	2.1	–
Mode choice (> 2 km)			
Public transport	16.9	18.3	–
Car	61.1	60.4	–
Bike	17.5	17.0	–
Walk	1.4	1.5	–
Other	3.1	2.8	–
Perceived safety at nearest station (0–10)			
< 6	0.3	0.2	–
6–6.9	10.7	11.1	–
7–7.9	72.0	70.9	–
8–8.9	17.1	17.8	–
9–10	0.0	0.0	–
Service headway, origin (percent of trips in dataset)			
< 5 min	19.0	19.9	–
5–10 min	48.2	49.9	–
11–15 min	5.8	5.7	–
16–20 min	5.1	5.3	–
21–30 min	7.0	6.6	–
> 30 min	14.8	12.5	–
Service headway, destination (percent of trips in dataset)			
< 5 min	19.2	20.0	–
5–10 min	47.6	49.8	–
11–15 min	5.7	5.6	–
16–20 min	5.6	5.5	–
21–30 min	7.0	6.7	–
> 30 min	14.8	12.5	–

Note that TU data only covers citizens of age 10–84 years

that stations located in low-income areas generally have lower perceived safety levels than those in higher-income areas.

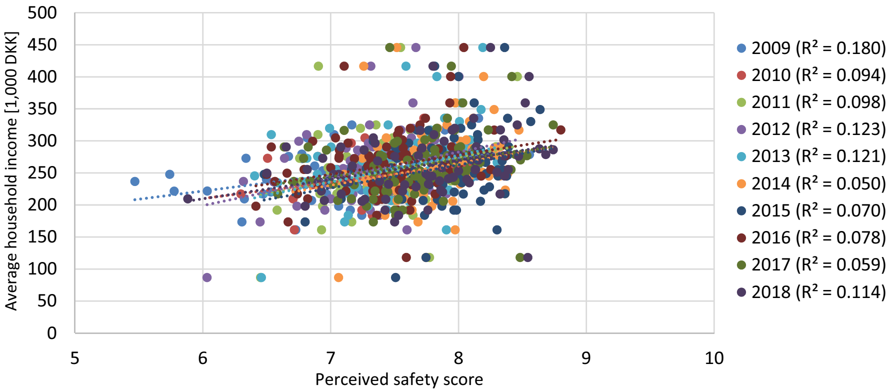

Fig. 1 Relationship between perceived safety at stations and the average income of households in the vicinity area of stations (data for different years plotted separately)

4 Analyses and results

This study deployed logistic regression using the SAS/STAT software, Version 9.4 (SAS Institute Inc 2015), for the analysis of the determinants of public transport mode choice, and specifically the influence of station vicinity and station characteristics. It was considered to deploy geographically weighted regression (GWR) to allow for the relationships between mode choice and the included dependent variables to vary by location. However, as we wanted to include several spatial dimensions in the analysis of each single mode choice, i.e. vicinity to nearest stops and stations at both origin and destination of each trip, it was preferred to include these as independent variables in a logistic regression. Both logit and probit models were estimated and yielded similar results in terms of significant parameters, which was not surprising (Ben-Akiva and Lerman 1985). For the reporting of the final model estimations, logit models were preferred due to the easier interpretation of coefficients as odds ratios are easily calculated by taking the exponential of the coefficients. A binary choice variable was created for each trip denoting whether public transport was chosen or not. No distinction was made between different modes of public transport, e.g. bus, suburban train, regional train, metro, etc. Hence, the results show which variables relate to the choice of public transport in a mode choice context.

As mentioned in Sect. 3.2 perceived safety data were not available for all combinations of stations and years in the dataset. Hence, two models were estimated. Model I included all 42,438 trips adhering to the assumptions described in the data section; however, they did not include perceived safety. Model II included those 19,286 trips for which perceived safety information was available for the nearest station, while also requiring the station being located within 1000 m of the trip origin. By this, the perceived safety was estimated using a sub-sample of 45% of the trips, whereas all other characteristics were estimated on the full sample. Note that this makes direct comparisons of the fit of the two models impossible.

Table 2 Overview of the characteristics included in the model estimations

Parameter	Type	Possible values	Reference value
Perceived safety	Discrete	Low (< 7) Medium (7–8) High (> 8)	Medium (7–8)
Service headway (rail)	Discrete	< 5 min 5–10 min 11–15 min 16–20 min 21–30 min > 30 min	> 30 min
Service headway (bus)	Continuous	–	–
Trip length	Continuous	–	–
LoS ratio	Continuous	–	–
Population density	Continuous	–	–
Gender	Discrete	Same as in Table 1	Female
Age	Discrete	Same as in Table 1	> 67
Education level	Discrete	Same as in Table 1	High school only
Employment status	Discrete	Same as in Table 1	Employed
Income	Continuous	–	–
Bicycle ownership	Discrete (binary)	0, 1	0
Car ownership	Discrete (binary)	0, 1	0
Driver's license	Discrete (binary)	0, 1	0
Station/stop vicinity dummies	Discrete (binary)	0, 1	0
Trip purpose fixed effects	Discrete	–	–
Year fixed effects	Discrete	–	–
Trip origin fixed effects	Discrete	–	–
Trip destination fixed effects	Discrete	–	–

An overview of the characteristics included in the final model estimations is reported in Table 2. All continuous variables were tested both as continuous covariates and by creating binary dummy covariates, hence considering potential linear and non-linear effects. As an example, perceived safety was originally measured on a 10-point Likert scale, but was converted into a discrete variable, i.e. low, medium and high perceived safety level. Similarly, service headway was measured in hourly departures for rail, which was converted into discrete headway intervals in the final estimations. Service headway for bus showed to be of no significance. Trip length, population density in the station vicinity areas, and the ratio between travel times for the specific trip using public transport and car, respectively, were included as continuous variables. Most of the respondents' socio-economic characteristics were included as binary dummy variables, except for household income, which was continuous. Similarly, vicinity to rail stations and bus stops was included as binary dummy variables using 200 m distance bands, e.g. whether a trip origin/destination was located within 0–200 m of a station/stop, 200–400 m of a station/stop, etc. Finally, we included explicitly fixed effects related to trip origin and destination, trip purpose, and the year in the model specification, as these characteristics are known to be associated to mode choice. Public transport usage is often higher in the city centre than in rural areas, all else being equal. Similarly, commute trips often have a higher public transport mode share, whereas business trips often have a lower one. In addition, public transport usage has yearly fluctuations due to factors that were not possible to consider explicitly, e.g. reliability of specific rail and bus lines. The fixed effects were incorporated in the models using k-1 binary variables, where k is the number of categories, e.g. number of trip purposes. With 23 trip purpose categories, 29 origin and 32 destination zones, and 11 years (2009–2019), a total number of 91 binary variables for the fixed effects was included in the models. These coefficients are not reported in the model results.

The main results of the model estimations for the mode choice of public transport are reported in Table 3 while the parameter estimates related to station vicinity are visualised in Fig. 2 (for Model I only). They confirm the hypothesis of perceived safety being correlated with public transport mode choice, in line with Delbosc and Currie (2012). Specifically, the results indicate, at a 95% significance level, that travellers are 16.1% less likely to choose public transport if the nearest station is associated with a low perception of safety and security compared to stations associated with a medium and high perception of safety and security, hence actually emphasising the importance of safe station environments. In addition, it should be noted that removing perceived safety from Model II resulted in a marginally lower model fit of $R^2 = 0.3349$ compared to the final $R^2 = 0.3352$.

However, the effect of perceived safety is notably smaller than that of service characteristics. For trips where the service headway at the closest train station to the origin is less than 5 min, the likelihood of choosing public transport is almost double as compared to that of a headway of more than 15 min (+99.6%). This is mainly the case of metro stations and large suburban train stations served by multiple lines. For service headways of 5–15 min, positive effects are also seen with decreasing effect as headway increases. No effects were seen for larger headways, hence suggesting that the positive effects from service frequency only occur in case of relatively frequent rail services. Similarly, no effects were seen for service frequency at the nearest bus stop, thus suggesting less attractiveness of bus services. In addition, the service frequency at the origin of the trip is more positively associated with the likelihood of choosing public transport than the service frequency at the destination. The use of threshold dummies provided a better model fit than using service frequency as a continuous explanatory variable, hence further suggesting a non-linear relationship between service frequency and the likelihood of choosing public transport. Thus, improving the service frequency at an already high frequency achieves a relatively larger increase in ridership than at lower service frequency. This could be due to passengers not needing to plan their trip when service frequency is sufficiently high.

In terms of socio-economic characteristics, the results revealed that men are 22.8% less likely to choose public transport than women, which is in accordance with most previous studies (Limtanakool et al. 2006; Beirão and Sarsfield Cabral

Table 3 Logistic logit regression results for the choice of public transport. 95% confidence level used

Variable name	Model I			Model II		
	Estimate	Odds ratio	p–value	Estimate	Odds ratio	p-value
Intercept	−0.821	0.440	0.1928	−0.655	0.519	0.3960
Trip characteristics						
Perceived safety, low (origin)	–	–	–	−0.175	0.839	0.0189
Service headway, < 5 min (orig.)	0.595	1.813	< 0.0001	0.691	1.996	< 0.0001
Service headway, 5–10 min (orig.)	0.436	1.546	< 0.0001	0.573	1.773	< 0.0001
Service headway, 11–15 min (orig.)	0.404	1.497	< 0.0001	0.504	1.656	0.0015
Service headway, < 5 min (dest.)	0.389	1.475	< 0.0001	0.327	1.386	< 0.0001
Service headway, 5–10 min (dest.)	0.254	1.289	< 0.0001	0.237	1.268	< 0.0001
Trip length (km)	0.049	1.051	< 0.0001	0.062	1.064	< 0.0001
LoS ratio (PT/car)	−0.709	0.492	< 0.0001	−0.780	0.459	< 0.0001
Population density in station area	−0.077	0.926	< 0.0001	−0.081	0.923	< 0.0001
Socio-economic characteristics						
Male	−0.269	0.764	< 0.0001	−0.259	0.772	< 0.0001
Age, 0–15 years	−0.773	0.462	< 0.0001	−0.414	0.661	0.0005
Age, 16–25 years	0.292	1.339	< 0.0001	0.317	1.372	< 0.0001
Income (1000 DKK per year)	−0.00173	0.998	< 0.0001	−0.00155	0.998	< 0.0001
Education, vocational	−0.420	0.657	< 0.0001	−0.378	0.685	< 0.0001
Education, university short	−0.235	0.790	0.0009	−0.226	0.798	0.0248
Education, university medium	−0.183	0.833	< 0.0001	−0.127	0.881	0.0142
Student	−0.430	0.651	< 0.0001	−0.346	0.708	< 0.0001
Retired	0.213	1.237	0.0006	0.229	1.257	0.0113
Bicycle ownership (dummy)	−0.216	0.806	< 0.0001	−0.241	0.786	< 0.0001
Car ownership (dummy)	−1.195	0.303	< 0.0001	−1.187	0.305	< 0.0001
Driver's license [dummy]	−1.174	0.309	< 0.0001	−1.054	0.349	< 0.0001
Trip purpose fixed effects	Yes					
Year fixed effects	Yes					
Geographical fixed effects	Yes (orig. and dest.)					
Number of observations	42,438			19,286		
Log likelihood	−14,341			−7332		
R^2 (McFadden)	0.3477			0.3352		

2007). Children choose public transport less often, probably because they normally travel with their parents—or walk or cycle to school. Young adults choose public transport more frequently, maybe due to being captive users. The same applies for pensioners. On the other hand, students are less likely to choose public transport, which might be due to the combination of public transport being relatively expensive in the Greater Copenhagen area and the large share of bicyclists. Hence,

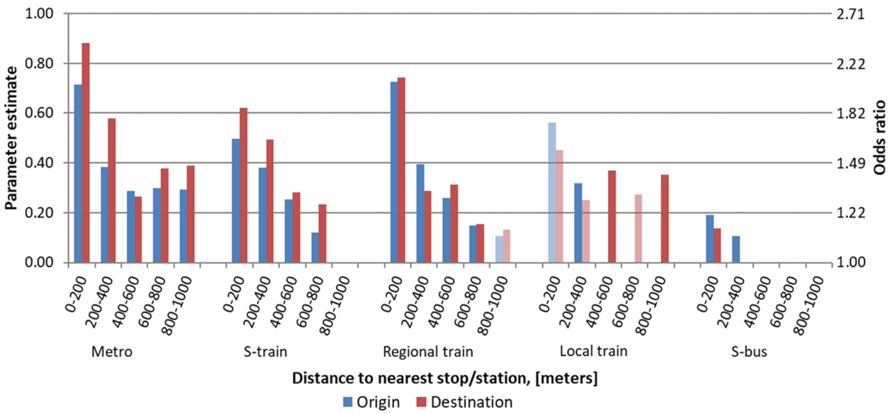

Fig. 2 Parameter estimates (left axis) and odds ratios (right axis) for vicinity to various public transport stops and stations (solid: 95% confidence level; transparent: 80% confidence level). Note that odds ratios are non-linear

students are probably more likely to choose their bicycle. Finally, the likelihood of choosing public transport decreases with household income. This is in accordance with most previous studies identified in the literature review.

There also seems to be a variation across respondents with different educational levels. Those with a vocational or short secondary background use public transport least frequently, compared to university graduates and those without secondary education, who are more likely to choose public transport. This is in line with previous research findings (Taylor et al. 2009). This might be explained by workplace location differences as high-education jobs are more frequently located in city centres that have good public transport coverage.

As expected, car ownership and the possession of a driver's license is negatively associated with choosing public transport, which is in line with previous research (Taylor et al. 2009; Delbosc and Currie 2012). Similar results are seen for bicycle ownership, which suggests that also bicycling is a competitor to public transport rather than being complementary. Also, the likelihood of choosing public transport increases with increasing trip length. This is likely due to public transport being more competitive on longer trips whereas access and egress times are substantial parts on shorter trips leading to low average travel times.

Close proximity to train stations and bus stops also had an effect on the likelihood of choosing public transport, however the effects depend on the various modes of the Copenhagen public transport network. Figure 2 shows the parameter estimates and related odds ratios graphically for the explanatory variables included in Model I. Note that odds ratio is obtained by taking the exponential to the parameter estimates, hence the secondary y axis is non-linear.

The largest effects are seen for trips with origin or destination within 200 m of metro stations, where the likelihood of choosing public transport is around double of that of trips located further than 1000 m from metro stations. This suggests that the metro is most successful in attracting passengers, even when controlling the high service frequency. This could be related to the high reliability of the metro. Similarly, the proximity to S-train stations is significantly related to a higher likelihood of choosing public transport, however in a slightly smaller magnitude, i.e. a 50–80% higher likelihood if trip origin or destination is within 0–400 m. Comparable results are seen for proximity to regional train stations with the largest effect of an approx. 100% higher likelihood of choosing public transport if the trip origin or destination is within 0–200 m. These stations are often served at lower service frequencies, but provide fast travel speeds from outside the Greater Copenhagen area to city centre locations. On the other hand, local train services seem to have limited effects, hence travellers do not perceive access to these stations as similarly attractive.

For bus stops the results are mixed. A small positive effect of an up to approx. 20% increased likelihood is observed for proximity to bus stops served by S-buses that run at faster speeds than other bus types. However, the effect is small and only for a very close proximity of less than 200 m, and the effect is even smaller from 200 to 400 m of the origin. No effects were observed for the proximity to bus stops served by A-buses and regular buses, hence suggesting that these bus services are less attractive. This suggests that travellers are more likely to choose public transport, across bus and rail services, if the service provided is fast and frequent.

Discussion and study limitations While the current study provides new insights on the influence of perceived safety on public transport mode choice it did have important limitations which future studies should address. First, the service frequency was included only for the nearest station, independent of type, and for the nearest bus stop of each type (A-, S-, and regular bus stops) at the origin and destination of each trip. Similarly, the perceived safety level was only included for the station nearest to the origin of the trip. Hence, the study implicitly assumes that passengers will base their decision to use public transport on service characteristics related to only their nearest train station and bus stops. As train stations are often located distantly from each other, this assumption is suitable in most cases, except in the city centre where stations are located closer to each other. Here some might prefer to use a slightly more distant metro station rather than an S-train station (or vice versa). For bus stops, this assumption is less suitable as bus stops are generally located closer to each other, especially in the city centre. This means that there may be several bus stops located almost similarly close to an origin or destination that the travellers can choose between depending on their destination. This might be the reason for service frequency at the nearest bus stop being insignificant in the model estimations. Hence, efforts could be made to improve this aspect, e.g. by taking into account characteristics from multiple stations and stops in the vicinity of the origin and destination of each trip.

Second, most of the characteristics related to the station layout and amenities did not significantly influence public transport mode choice. Hence, these are not reported. It was hypothesised that improved station layout and availability of shops might entail more attractive stations that were then more likely to be used by the travellers. Both because travellers have the possibility to spend their time efficiently while waiting, and because such stations might be perceived as being safer and more secure. However, the results did not reveal any significant effects. Possible reasons for this result could be that such an effect is more dependent on detailed characteristics related to the shops, e.g. opening hours, number of customers, etc. rather than solely whether a shop is present or not. This could be analysed in more detail.

Thirdly, the model estimations included objective service characteristics, whereas individuals' travel attitudes and perceived quality of service in terms of satisfaction levels were not included as they were not available. The results are thus an average over the passenger population.

5 Conclusions

The current study analysed the likelihood of travellers to choose public transport using logistic regression and utilising a large-scale travel survey from the Greater Copenhagen area. The results confirmed the hypothesis that perceived safety at stations is positively associated with choosing public transport. Specifically, a low perceived safety was negatively related to choosing public transport, hence suggesting that a low perceived safety creates unease for passengers. However, the effects of a low perceived safety were smaller than those related to the service frequency. No effects were observed from any of the station characteristics, e.g. availability of shops and station layout. Hence, the findings suggest a larger influence from service characteristics rather than station characteristics.

The study also revealed the influence of station vicinity, as proximity to rail stations was associated with a higher likelihood of choosing public transport, even when controlling for service frequency. The largest effects were observed for close proximity to metro stations, but proximity to S-train and regional train stations had an almost similarly large influence, whereas proximity to high-class bus services was least positively associated. Hence, at an aggregate level these findings suggest that rail-based public transport is more attractive from the passengers' point of view, even when controlling for service frequency. This could be due to higher travel speeds, reliability and comfort, as these characteristics were not controlled for. However, this should be investigated in more detail if general conclusions are to be drawn.

Furthermore, while the results showed that the aggregated average household income in the vicinity of the stations was significantly positively correlated with perceived safety, it was not directly related to the choice of public transport. This suggests that socio-demographic characteristics in station areas relate to the perception of the areas, hence possibly indirectly relating to the use of public transport.

Finally, to attract more passengers to the public transport system, the findings from this study suggest that it is more relevant to focus on improving service characteristics, such as service frequency and network coverage, rather than on perceived safety levels, especially considering that the effects of perceived safety were solely significant for stations with relatively low perceived safety levels. On the other hand, improving service characteristics in terms of service frequency might be associated with increased operation costs, whereas increased perceived safety levels at stations might be achieved in combination with urban planning initiatives by creating more attractive station areas. In that sense, ensuring that station areas are not perceived as unsafe by improving the surrounding urban space may be worthwhile and may also influence public transport ridership positively.

Acknowledgements The authors would like to thank the IPTOP (Integrated Public Transport Optimisation and Planning) research project funded by Innovation Fund Denmark for financing this study.

References

Abdul Hamid N, Tan P-L, Mohamad Zali MF et al (2015) Safety and security needs of commuter rail services—travellers' perceptions. J East Asia Soc Transp Stud 11:1495–1506. https://doi.org/10.11175/easts.11.1495

Abenoza RF, Cats O, Susilo YO (2017) Travel satisfaction with public transport: determinants, user classes, regional disparities and their evolution. Transp Res Part A Policy Pract 95:64–84. https://doi.org/10.1016/j.tra.2016.11.011

Andridge RR, Little RJA (2010) A review of hot deck imputation for survey non-response. Int Stat Rev 78:40–64. https://doi.org/10.1111/j.1751-5823.2010.00103.x

Badiora AI, Ojewale OS, Okunola OH (2015) Perceived risk and fear of crime in public transport nodes: the experience from Nigerian transit environment. Int J Crim Justice Sci 10(2):139–151

Barton MS, Gibbons J (2017) A stop too far: how does public transportation concentration influence neighbourhood median household income? Urban Stud 54:538–554. https://doi.org/10.1177/0042098015593462

Beirão G, Sarsfield Cabral JA (2007) Understanding attitudes towards public transport and private car: a qualitative study. Transp Policy 14:478–489. https://doi.org/10.1016/j.tranpol.2007.04.009

Ben-Akiva M, Lerman S (1985) Discrete Choice Analysis: Theory and Applications to Travel Demand. MIT Series in Transportation Studies. The MIT Press, Cambridge

Blainey S, Mulley C (2013) Using geographically weighted regression to forecast rail demand in the Sydney region. Australas Transp Res Forum, ATRF 2013 Proc 1–16

Börjesson M (2012) Valuing perceived insecurity associated with use of and access to public transport. Transp Policy 22:1–10. https://doi.org/10.1016/j.tranpol.2012.04.004

Boschmann EE, Brady SA (2013) Travel behaviors, sustainable mobility, and transit-oriented developments: a travel counts analysis of older adults in the Denver, Colorado metropolitan area. J Transp Geogr 33:1–11. https://doi.org/10.1016/j.jtrangeo.2013.09.001

Buehler R (2011) Determinants of transport mode choice: a comparison of Germany and the USA. J Transp Geogr 19:644–657. https://doi.org/10.1016/j.jtrangeo.2010.07.005

Cantwell M, Caulfield B, O'Mahony M (2009) Examining the factors that impact public transport commuting satisfaction. J Public Transp 12(2):1–21. https://doi.org/10.5038/2375-0901.12.2.1

Ceccato V (2014) Safety on the move: crime and perceived safety in transit environments. Secur J 27:127–131. https://doi.org/10.1057/sj.2014.11

Cervero R, Murakami J, Miller M (2010) Direct ridership model of bus rapid transit in Los Angeles County, California. Transp Res Rec J Transp Res Board 2145:1–7. https://doi.org/10.3141/2145-01

Chakraborty A, Mishra S (2013) Land use and transit ridership connections: implications for state-level planning agencies. Land Use Policy 30:458–469. https://doi.org/10.1016/j.landusepol.2012.04.017

Chen X, Zhao J (2013) Bidding to drive: car license auction policy in Shanghai and its public acceptance. Transp Policy 27:39–52. https://doi.org/10.1016/j.tranpol.2012.11.016

Chiou YC, Jou RC, Yang CH (2015) Factors affecting public transportation usage rate: geographically weighted regression. Transp Res Part A Policy Pract 78:161–177. https://doi.org/10.1016/j.tra.2015.05.016

Christiansen H (2015) Documentation of the Danish National Travel Survey. Kgs. Lyngby

Cordera R, Canales C, dell'Olio L, Ibeas A (2015) Public transport demand elasticities during the recessionary phases of economic cycles. Transp Policy 42:173–179. https://doi.org/10.1016/j.tranpol.2015.05.022

Cozens P, van der Linde T (2015) Perceptions of crime prevention through environmental design (CPTED) at Australian Railway Stations. J Public Transp 18(4):73–92. https://doi.org/10.5038/2375-0901.18.4.5

Crampton G (2002) International comparison of urban light rail systems: the roles of integrated ticketing, pedestrianisation, and population density. Proc ERSA 2002 Conf Dortmund, Ger Paper 167

Crime Concern (2004) People's perceptions of personal security and their concerns about crime on public transport: research findings. London: Department for Transport

Currie G, Ahern A, Delbosc A (2011) Exploring the drivers of light rail ridership: an empirical route level analysis of selected Australian, North American and European systems. Transportation 38:545–560. https://doi.org/10.1007/s11116-010-9314-9

De Oña J, De Oña R, Eboli L, Mazzulla G (2013) Perceived service quality in bus transit service: a structural equation approach. Transp Policy 29:219–226. https://doi.org/10.1016/j.tranpol.2013.07.001

Delbosc A, Currie G (2012) Modelling the causes and impacts of personal safety perceptions on public transport ridership. Transp Policy 24:302–309. https://doi.org/10.1016/j.tranpol.2012.09.009

Derrible S, Kennedy C (2009) Network analysis of world subway systems using updated graph theory. Transp Res Rec J Transp Res Board 2112:17–25. https://doi.org/10.3141/2112-03

Dyrberg MB, Christensen CB (2015) Transfers in public transport route choice models. Master's thesis. DTU Transport, Technical University of Denmark

Dziekan K, Kottenhoff K (2007) Dynamic at-stop real-time information displays for public transport: effects on customers. Transp Res Part A Policy Pract 41:489–501. https://doi.org/10.1016/j.tra.2006.11.006

Eboli L, Mazzulla G (2015) Relationships between rail passengers' satisfaction and service quality: a framework for identifying key service factors. Public Transp 7:185–201. https://doi.org/10.1007/s12469-014-0096-x

Eboli L, Forciniti C, Mazzulla G (2018a) Formative and reflective measurement models for analysing transit service quality. Public Transp 10:107–127. https://doi.org/10.1007/s12469-017-0168-9

Eboli L, Forciniti C, Mazzulla G (2018b) Spatial variation of the perceived transit service quality at rail stations. Transp Res Part A Policy Pract 114:67–83. https://doi.org/10.1016/j.tra.2018.01.032

Ewing R, Cervero R (2010) Travel and the built environment. J Am Plan Assoc 76:265–294. https://doi.org/10.1080/01944361003766766

Fan Y, Guthrie A, Levinson D (2016) Waiting time perceptions at transit stops and stations: Effects of basic amenities, gender, and security. Transp Res Part A Policy Pract 88:251–264. https://doi.org/10.1016/j.tra.2016.04.012

Fellesson M, Friman M (2012) Perceived satisfaction with public transport service in nine European cities. J Transp Res Forum 47(3):93–103

Guerra E, Cervero R, Tischler D (2012) Half-mile circle: does it best represent transit station catchments? Transp Res Rec J Transp Res Board. https://doi.org/10.3141/2276-12

Guirao B, García-Pastor A, López-Lambas ME (2016) The importance of service quality attributes in public transportation: narrowing the gap between scientific research and practitioners' needs. Transp Policy 49:68–77. https://doi.org/10.1016/j.tranpol.2016.04.003

Guo Z, Wilson NHM (2011) Assessing the cost of transfer inconvenience in public transport systems: a case study of the London Underground. Transp Res Part A Policy Pract 45:91–104. https://doi.org/10.1016/j.tra.2010.11.002

Gutiérrez J, Cardozo OD, García-Palomares JC (2011) Transit ridership forecasting at station level: an approach based on distance-decay weighted regression. J Transp Geogr 19:1081–1092. https://doi.org/10.1016/j.jtrangeo.2011.05.004

Heikkinen S, Henriksson P (2013) Äldres Resvanor—Äldre Trafikanter Som Heterogen Grupp Och Framtida Forskningsbehov

Hjorthol R (2013) Transport resources, mobility and unmet transport needs in old age. Ageing Soc 33:1190–1211. https://doi.org/10.1017/S0144686X12000517

Hong J, Li T, Park D (2017) A statistical approach for a station-level subway ridership estimation: focus on the impact of bus demand and commercial business characteristics. World Acad Sci Eng Technol Int J Transp Veh Eng 4

Imaz A, Nurul Habib KM, Shalaby A, Idris AO (2015) Investigating the factors affecting transit user loyalty. Public Transp 7:39–60. https://doi.org/10.1007/s12469-014-0088-x

Ingvardson JB, Nielsen OA (2018) How urban density, network topology and socio-economy influence public transport ridership: empirical evidence from 48 European metropolitan areas. J Transp Geogr 72:50–63. https://doi.org/10.1016/j.jtrangeo.2018.07.002

Iseki H, Taylor B (2015) Style versus service? An analysis of user perceptions of transit stops and stations. J Public Transp 13(3):23–48. https://doi.org/10.5038/2375-0901.13.3.2
Jun MJ, Choi K, Jeong JE et al (2015) Land use characteristics of subway catchment areas and their influence on subway ridership in Seoul. J Transp Geogr 48:30–40. https://doi.org/10.1016/j.jtrangeo.2015.08.002
Kim S, Ulfarsson GF, Todd Hennessy J (2007) Analysis of light rail rider travel behavior: impacts of individual, built environment, and crime characteristics on transit access. Transp Res Part A Policy Pract 41:511–522. https://doi.org/10.1016/j.tra.2006.11.001
Kuby M, Barranda A, Upchurch C (2004) Factors influencing light-rail station boardings in the United States. Transp Res Part A Policy Pract 38:223–247. https://doi.org/10.1016/j.tra.2003.10.006
Levinson D, Zhu S (2013) A portfolio theory of route choice. Transp Res Part C Emerg Technol 35:232–243. https://doi.org/10.1016/j.trc.2013.03.001
Limtanakool N, Dijst M, Schwanen T (2006) The influence of socioeconomic characteristics, land use and travel time considerations on mode choice for medium- and longer-distance trips. J Transp Geogr 14:327–341. https://doi.org/10.1016/j.jtrangeo.2005.06.004
Liu C, Erdogan S, Ducca FW (2016) How to increase rail ridership in Maryland? Direct ridership models (DRM) for policy guidance. J Urban Plan Dev 142:1–10. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000340
Loukaitou-Sideris A (2014) Fear and safety in transit environments from the women's perspective. Secur J 27:242–256. https://doi.org/10.1057/sj.2014.9
Lynch G, Atkins S (1988) The influence of personal security fears on women's travel patterns. Transportation 15:257–277. https://doi.org/10.1007/BF00837584
Masoumi HE, Fastenmeier W (2016) Perceptions of security in public transport systems of Germany: prospects for future research. J Transp Secur 9:105–116. https://doi.org/10.1007/s12198-016-0169-y
Mouwen A (2015) Drivers of customer satisfaction with public transport services. Transp Res Part A Policy Pract 78:1–20. https://doi.org/10.1016/j.tra.2015.05.005
Nkurunziza A, Zuidgeest M, Brussel M, Van den Bosch F (2012) Spatial variation of transit service quality preferences in Dar-es-Salaam. J Transp Geogr 24:12–21. https://doi.org/10.1016/j.jtrangeo.2012.06.001
Pasha M, Rifaat SM, Tay R, De Barros A (2016) Effects of street pattern, traffic, road infrastructure, socioeconomic and demographic characteristics on public transit ridership. KSCE J Civ Eng 20:1017–1022. https://doi.org/10.1007/s12205-016-0693-6
Passagerpulsen (2017) De Nationale Passagertilfredshedsundersøgelser (tog)/National Passenger Satisfaction Surveys (train) 17:1–92 **(in Danish)**
Paulley N, Balcombe R, Mackett R et al (2006) The demand for public transport: the effects of fares, quality of service, income and car ownership. Transp Policy 13:295–306. https://doi.org/10.1016/j.tranpol.2005.12.004
SAS Institute Inc (2015) The LOGISTIC Procedure. 259
Şimşekoğlu Ö, Nordfjærn T, Rundmo T (2015) The role of attitudes, transport priorities, and car use habit for travel mode use and intentions to use public transportation in an urban Norwegian public. Transp Policy 42:113–120. https://doi.org/10.1016/j.tranpol.2015.05.019
Smith MJ (2008) Addressing the security needs of women passengers on public transport. Secur J 21:117–133. https://doi.org/10.1057/palgrave.sj.8350071
Spears S, Houston D, Boarnet MG (2013) Illuminating the unseen in transit use: a framework for examining the effect of attitudes and perceptions on travel behavior. Transp Res Part A Policy Pract 58:40–53. https://doi.org/10.1016/j.tra.2013.10.011
Stuart KR, Mednick M, Bockman J (2007) Structural equation model of customer satisfaction for the New York City subway system. Transp Res Rec J Transp Res Board 1735:133–137. https://doi.org/10.3141/1735-16
Taylor BD, Fink CNY (2013) Explaining transit ridership: What has the evidence shown? Transp Lett 5:15–26. https://doi.org/10.1179/1942786712z.0000000003
Taylor BD, Miller D, Iseki H, Fink C (2009) Nature and/or nurture? Analyzing the determinants of transit ridership across US urbanized areas. Transp Res Part A Policy Pract 43:60–77. https://doi.org/10.1016/j.tra.2008.06.007
van Lierop D, El-Geneidy A (2016) Enjoying loyalty: the relationship between service quality, customer satisfaction, and behavioral intentions in public transit. Res Transp Econ 59:50–59. https://doi.org/10.1016/j.retrec.2016.04.001

van Lierop D, Badami MG, El-Geneidy AM (2018) What influences satisfaction and loyalty in public transport? A review of the literature. Transp Rev 38:52–72. https://doi.org/10.1080/01441647.2017.1298683

Zhao J, Deng W, Song Y, Zhu Y (2013) What influences Metro station ridership in China? Insights from Nanjing. Cities 35:114–124. https://doi.org/10.1016/j.cities.2013.07.002