The influence of frequency on route choice in mixed schedule- and frequency-based public transport systems – The case of the Greater Copenhagen Area

Morten Eltved · Otto Anker Nielsen · Thomas Kjær Rasmussen

Abstract This study presents an in-depth analysis of the importance of frequency and published timetables when describing passengers' route choice in mixed schedule- and frequency-based public transport systems. From a passenger perspective the frequency of services are important, as this define the possible departure/arrival times and influence on the waiting times before boarding the first vehicle. Frequency is also important in networks with mixed schedule- and frequency-based services, as the passengers need to take into account the uncertainty when transferring between the two types of services. This study provides insights into the importance of frequency on route choice in networks with a wide range of frequencies. The outcome is a description of the importance of frequency on passengers' route choice and a more detailed description of passengers' route choice when considering the difference between frequency- and schedule-based services from a passenger perspective.

Keywords: Public transport route choice · Passenger preferences · Travel survey · Discrete choice model · Frequency · Mixed schedule- and frequency-based network

Morten Eltved
Department of Management Engineering, Technical University of Denmark
Kongens Lyngby, Denmark
Email: morel@dtu.dk

Otto Anker Nielsen
Department of Management Engineering, Technical University of Denmark
Kongens Lyngby, Denmark
Email: oani@dtu.dk

Thomas Kjær Rasmussen
Department of Management Engineering, Technical University of Denmark
Kongens Lyngby, Denmark
Email: tkra@dtu.dk

1 Introduction

The public transport system in most metropolitan cities, including the Greater Copenhagen Area, is a mix of high and low frequency services where the published timetable for some lines is schedule-based while being frequency-based for others. The passengers are therefore often in a situation where the route choice includes options where both schedule- and frequency-based services are viable alternatives relevant to consider, and may be used as components in a given route. The combination of the two types of services, independent of public transport mode, leads to a more complex route choice, where the frequency of services are important for various reasons, e.g. in relation to transfers.

In public transport assignment models the typical components of the utility function are the quantifiable time components (in-vehicle, first waiting time, waiting time at transfers, walking time and hidden waiting time) as well as a transfer penalty and in some applications also the ticket price (Gentile and Noekel, 2016, chap. 4). Other factors that affects passengers' route choice are in-vehicle crowding, level changes and other attributes at transfer stations as well as topological characteristics for the spatial dimension of a trip (Raveau et al., 2014). Implicitly, the impact of frequency on route choice has typically been captured by the hidden waiting time and waiting time in a linear way. However, as it was shown in Anderson et al. (2014), the specification of a piecewise linear functional form for the headway of the most low frequency leg of a trip resulted in a significant parameter and a better model fit.

In this paper we utilise a large disaggregate dataset on observed behaviour in the Greater Copenhagen Area. The results demonstrate, that the model fit to observed behaviour can be improved further by (i) detailing the description of the frequency by more advanced functional forms in the utility specification; (ii) using new knowledge identified in (Ingvardson, 2017) about passengers' waiting time at the first station to enrich the detailed dataset and; (iii) relating passengers' route choice to the published timetables to identify preferences for frequency- and schedule-based services.

2 Data foundation and methodology

The dataset used in this study consists of 5,121 observed routes done by public transport. The data is collected in the years 2009-2011 as part of the Danish National Transport Survey (Center for Transport Analytics DTU, 2017). The observed routes have been matched to a schedule-based representation of the public transport network as described in Anderson and Rasmussen (2010). A choice set of alternatives corresponding to each observed route have been generated using a simulation-based choice set generation method described in Rasmussen et al. (2016). The final choice sets consist of between 18-200 alternatives for each observation with an average of 128 alternatives per observed route.

Description of network

The public transport network in the Copenhagen Region is a mix of schedule- and frequency-based services operating with headways in the range 2-90 minutes. The frequency-based services are primarily the metro operating with a headway of 2-4 minutes during peak hour and the so-called "A-busses" with headways between 3-8 minutes during peak hours operating in the most densely populated part of Copenhagen. The rest of the buses, regional and suburban trains in the Greater Copenhagen Area operate with a published schedule with headways between 5-90 minutes. The figures below show examples of the published timetable for a frequency- and a schedule-based bus line. Note in this case the lower frequency of the frequency-based bus line compared to the schedule-based bus line.

3A — mandag - fredag

Nordhavn st.	Trianglen	Elmegade	Aboulevard	Vesterbrogade	Enghave st. (Enghavevej)	Sydhavn st.	Kgs. Enghave (Valbyparken)
4.50	4.55	5.00	5.03	5.09	5.13	5.15	5.21
5.10	5.15	5.20	5.23	5.29	5.33	5.35	5.41
5.30	5.35	5.40	5.43	5.49	5.53	5.55	6.01
5.40	5.45	5.50	5.53	5.59	6.03	6.05	6.11
5.50	5.55	6.00	6.03	6.09	6.13	6.15	6.21
6.00	6.05	6.10	6.13	6.19	6.23	6.25	6.31
6.09	6.14	6.19	6.22	6.28	6.32	6.34	6.40
6.19	6.24	6.29	6.32	6.38	6.42	6.44	6.50
6.28	6.33	6.39	6.42	6.48	6.52	6.54	7.00
6.36	6.42	6.48	6.51	6.57	7.01	7.03	7.10
6.44	6.51	6.57	7.00	7.07	7.11	7.13	7.20
6.52	6.59	7.05	7.09	7.16	7.20	7.22	7.29
Interval:				6-8 min			
17.15	17.22	17.29	17.33	17.40	17.45	17.47	17.53
17.23	17.30	17.37	17.41	17.48	17.52	17.54	18.00

150S — mandag - fredag

Kokkedal St.	Fredensborg Rådhus	Bolbrovej	Hovedgaden	Gl. Holte (Holmevdlej)	Nærum St.	Klampenborgvej	Ryparken St.	Hans Knudsens Plads	Nørreport St.
5.25	5.30	5.33	5.37	—	5.48	5.54	6.04	6.05	6.14
5.46	5.51	5.54	5.58	—	6.09	6.15	6.25	6.26	6.36
6.04	6.09	6.12	6.16	—	6.27	6.33	6.43	6.44	6.54
6.14	6.19	6.22	6.26	—	6.37	6.43	6.53	6.54	7.05
6.24	6.29	6.32	6.36	—	6.47	6.53	7.03	7.04	7.15
6.33	6.38	6.41	6.45	—	6.57	7.03	7.14	7.15	7.26
—	—	—	—	—	7.05	7.11	7.22	7.23	7.35
6.45	6.50	6.53	6.58	—	7.10	7.16	7.27	7.28	7.40
—	—	—	—	7.06	7.16	7.22	7.33	7.34	7.46
6.55	7.00	7.03	7.08	—	7.21	7.27	7.38	7.39	7.51
—	—	—	—	—	7.26	7.32	7.43	7.44	7.56
7.05	7.11	7.14	7.19	—	7.32	7.38	7.50	7.51	8.03
—	—	—	—	—	7.37	7.43	7.55	7.56	8.08
7.15	7.21	7.24	7.29	—	7.43	7.49	8.01	8.02	8.14
—	—	—	—	—	7.49	7.55	8.07	8.08	8.20
7.25	7.31	7.34	7.39	—	7.55	8.01	8.13	8.14	8.26
—	—	—	—	7.50	8.00	8.06	8.18	8.19	8.31
7.35	7.41	7.44	7.49	—	8.05	8.11	8.23	8.24	8.36
—	—	—	—	—	8.10	8.16	8.28	8.29	8.41
7.45	7.51	7.54	7.59	—	8.15	8.21	8.33	8.34	8.46
—	—	—	—	8.10	8.20	8.26	8.38	8.39	8.51
7.55	8.01	8.04	8.09	—	8.25	8.31	8.42	8.43	8.55
—	—	—	—	—	8.32	8.38	8.49	8.49	9.02

Figure 1 - Example of a frequency-based bus (3A between 7am-5pm) and a schedule-based service (150S) (Movia, 2011)

In the figure below an overview of the public transport system in the Greater Copenhagen Area is seen.

Figure 2 - Schedule-based (SB) and frequency-based (FB) services
in the Greater Copenhagen Area

Characteristics of observed routes

The observed routes are distributed across the whole case-study area, and have a large variation in its components, as indicated in Table 1. Note that the average waiting time is rather low since a large share of the observations do not have any transfers. The access/egress time also includes the hidden waiting time, as the model assumes that passengers arrive to the first stop at the time of departure. The waiting time at the first stop will be included in the final estimation, using the estimated passenger arrival rates found in (Ingvardson, 2017), where the waiting time at the first stop depends on the headway and service type of the first leg.

Table 1 - Trip characteristics for observed routes

Trip component	Mean	Std. dev.
In-vehicle time total	20.21	13.76
In-vehicle time bus	8.25	11.08
In-vehicle time SB bus	6.14	10.33
In-vehicle time FB bus	2.11	5.91
In-vehicle time metro	1.39	3.55
In-vehicle train	10.57	13.66
Nb. of transfers	0.48	0.64
Waiting time at transfers	2.51	6.10
Walking time	0.97	1.58
Access/egress	12.78	9.36
Headway of first leg	5.94	8.15
Highest headway in trip	7.16	7.71
Include frequency-based service (dummy)	0.34	0.47
Total number of observations	5,121	

Estimation methodology

With the characteristics of the observed routes and the alternatives generated, we estimate a Path Size Correction Logit discrete choice methodology as described in Bovy et al. (2008). The utility of an alternative k in the choice set C_n for each observed route n is described with the following utility specification:

$$U_{kn} = V_{kn} + \epsilon_{kn} \qquad \forall\, K \in C_n$$

where, V_{kn} is the deterministic part of the utility and ϵ_{kn} is the random utility assumed to be gumbel distributed. The deterministic part of the utility V_{kn} is specified as:

$$V_{kn} = \sum_m \beta_{IVT,m} IVT_{mkn} + \sum_c \beta_{t,c} t_{ckn} + \sum_q \beta_{y,q} y_{qkn}$$

where, IVT_{mkn} is the in-vehicle time for component m, t_{ckn} is the time component c not related to in-vehicle time (e.g., waiting, walking, access/egress and headway) and y_{qkn} is component q not related to time (e.g., path size correction factor, transfer penalties and dummy variable for trips including frequency-based services). The path size correction factor is calculated for each alternative k as:

$$PSC_{kn} = -\sum_{a \in \Gamma_k} \left(\frac{L_a}{L_k} \ln \sum_{l \in C_n} \delta_{al} \right)$$

where, L_a is the length of link a, L_k is the length of route k, Γ_{kn} is the set of links belonging to route k, δ_{al} is a dummy connecting the link and route and is equal to one if route l uses link a and otherwise zero. The utility specification including path size

correction is then giving the following choice probability of route k for observation n:

$$P_{kn} = \frac{\exp(V_{kn} + \beta_{PSC} * PSC_{kn})}{\sum_{l \in C_n} \exp(V_{ln} + \beta_{PSC} * PSC_{ln})}$$

where, PSC_{kn} and PSC_{ln} are respectively path size correction factors for routes k and l.

4 Expected findings

Anderson et al. (2014) showed that the frequency is highly significant when describing passengers' route choice preferences. The present study focuses on revealing additional information related to the influence of the frequency and notably also the difference between schedule- and frequency-based services. Moreover, the findings relate to the following elements:

Tests of the importance of frequency in passengers route choice
Different functional forms of the specification of the frequency in the utility function are tested. This includes tests for piecewise linear functions, logarithmic and exponential forms as well as a non-linear spline functional form as specified in Rich (2015). The work also focuses on how various combinations of the frequency at different legs in a trip influences passengers' route choice.

More disaggregate representation of first waiting time and hidden waiting time
The dataset is enriched with the estimated passenger arrival rates found in Ingvardson (2017). This is done to give a better representation of the hidden waiting time and the first waiting time (at stop), which may vary quite significantly between schedule- and frequency-based services and thereby also influence the route choice. Ingvardson (2017) used a large sample of Automatic Fare Collection data (Rejsekort A/S, 2017), and found that passengers at schedule-based services with a headway of 5 minutes or more do not arrive randomly uniform, as indicated in Figure 3. The average waiting time is significantly lower than half of the headway implying that some of the waiting time must be considered as hidden waiting time, which other studies have shown to have a lower value of time (Fosgerau et al., 2007). For frequency-based services on the other hand, Ingvardson (2017) shows that passengers which have a frequency-based service as their first leg arrive uniformly. This has the implication that their hidden waiting time is zero and their waiting time is half headway of the frequency-based service. This could have implications on the preferences between schedule- and frequency-based services as well as for the tendency to prefer high frequent services compared to low frequent.
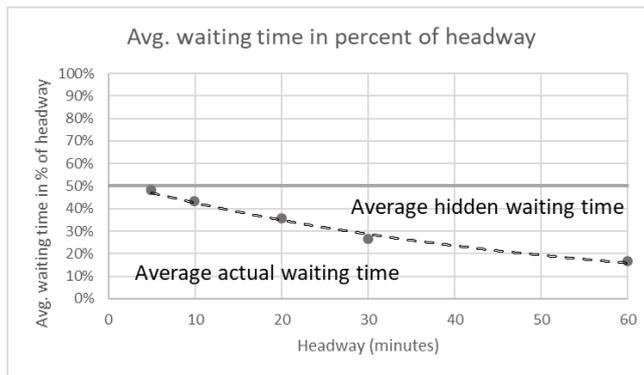
Figure 3 – Average actual waiting and hidden waiting time in percent
of the headway for schedule-based services (Ingvardson, 2017)

**Differences between timetables represented as frequency- and schedule-based
services**

The study additionally investigate whether passengers' preferences differ when the
timetable of a service is published as schedule- or frequency-based. The hypothesis
is, that passengers will in general have a preference for frequency-based services as
these are high frequent, but when correcting for the frequency of the lines in the utility
specification, the expectation is, that passengers prefer schedule-based services as
they can time their arrival.

Conclusion and future work

This study estimates a disaggregate model for passenger preferences in public
transport route choice, especially with focus on a rich description of the importance
of frequency of services and the type of timetable published. The preliminary results
show, that there are evidence that including a detailed description of the frequency in
the utility specification as well as distinguishing better between hidden and first
waiting time as dependent of service type improves the model fit, and give an even
better description of passengers' preferences in the Greater Copenhagen Area. The
consideration between schedule- and frequency-based services can potentially give a
better understanding of passengers' choice of services and can help to improve the
planning of the public transport system.

References

Anderson, M.K., Nielsen, O.A., Prato, C.G., 2014. Multimodal route choice models of public transport passengers in the Greater Copenhagen Area. EURO J. Transp. Logist. 1–25. doi:10.1007/s13676-014-0063-3

Anderson, M.K., Rasmussen, T.K., 2010. Matching Observed Public Route Choice Data to a {GIS} Network, in: Trafikdage På Aalborg Universitet. pp. 1–12.

Bovy, P.H.L., Bekhor, S., Prato, C.G., 2008. The Factor of Revisited Path Size: Alternative Derivation. Transp. Res. Rec. J. Transp. Res. Board 2076, 132–140. doi:10.3141/2076-15

Center for Transport Analytics DTU, 2017. Transportvaneundersøgelsen - TU [WWW Document]. URL http://www.modelcenter.transport.dtu.dk/Transportvaneundersoegelsen (accessed 12.12.17).

Fosgerau, M., Hjorth, H., Lyk-Jensen, S.V., 2007. The Danish Value of Time Study (Final Report).

Gentile, G., Noekel, K., 2016. Modelling Public Transport Passenger Flows in the Era of Intelligent Transport Systems. Springer. doi:10.1007/978-3-319-25082-3

Ingvardson, J.B., 2017. Attractiveness of Public Transport in a Metropolitan Setting. PhD thesis at Technical University of Denmark.

Movia, 2011. Samlet køreplan for Movia H 2011.

Rasmussen, T.K., Anderson, M.K., Nielsen, O.A., Prato, C.G., 2016. Timetable-based simulation method for choice set generation in large-scale public transport networks. Eur. J. Transp. Infrastruct. Res. 16, 467–489.

Raveau, S., Guo, Z., Muñoz, J.C., Wilson, N.H.M., 2014. A behavioural comparison of route choice on metro networks: Time, transfers, crowding, topology and socio-demographics. Transp. Res. Part A 66, 185–195. doi:10.1016/j.tra.2014.05.010

Rejsekort A/S, 2017. What is Rejsekort? [WWW Document]. URL http://www.rejsekort.dk/om-rejsekort/hvad-er-rejsekort.aspx (accessed 12.22.17).

Rich, J., 2015. A spline function class suitable for transport demand models, in: Presented at hEART 2015. doi:10.13140/RG.2.1.5094.6003