Walking and bicycle catchment areas of tram stops: factors and insights

Lotte Rijsman
Department of Transport and Planning
Delft University of Technology
Delft, The Netherlands
lotterijsman@gmail.com

Niels van Oort
Department of Transport and Planning
Delft University of Technology
Delft, The Netherlands
N.vanOort@tudelft.nl

Danique Ton
Department of Transport and Planning
Delft University of Technology
Delft, The Netherlands
D.Ton@tudelft.nl

Serge Hoogendoorn
Department of Transport and Planning
Delft University of Technology
Delft, The Netherlands
S.P.Hoogendoorn@tudelft.nl

Eric Molin
Department of Transport and Logistics
Delft University of Technology
Delft, The Netherlands
E.J.E.Molin@tudelft.nl

Thomas Teijl
Department of Travelers
HTM Personenvervoer B.V.
The Hague, The Netherlands
T.Teijl@htm.nl

***Abstract*—Pollution and congestion are important issues in urban mobility. These can potentially be solved by multimodal transport, such as the bicycle-transit combination, which benefits from the flexible aspect of the bicycle and the wider spatial range of public transport. In addition, the bicycle can increase the catchment areas of public transport stops. Most transit operators consider a fixed 400m buffer catchment area. Currently, not much is known about what influences the size of catchment areas, especially for the bicycle as a feeder mode. Bicycles allow for reaching a further stop in order to avoid a transfer, but it is not clear whether travelers actually do this. This paper aims to fill this knowledge gap by assessing which factors affect feeder distance and feeder mode choice. Data are collected by an on-board transit revealed preference survey among tram travelers in The Hague, The Netherlands. Both regression models and a qualitative analysis are performed to identify the factors that influence feeder distance and feeder mode choice. Results show that the median walking feeder distance is 380m, and the median cycling feeder distance is 1025m. The tram stop density and chosen feeder mode are most important in feeder distance. For feeder mode choice, the following factors are found to be influential: tram stop density, availability of a bicycle, and frequency of cycling of the tram passenger. Furthermore, the motives of respondents for choosing a stop further away are mostly related to the quality of the transit service and comfort matters, of which avoiding a transfer is named most often. In contrast, the motives for cycling relate mostly to travel time reduction and the built environment. Three important barriers for the bicycle-tram combination have been discovered: unavailability of a bicycle, insufficient and unsafe bicycle parking places. Infrequent users of the bicycle-tram combination are more inclined to travel further to a stop that suits them better.**

Keywords— feeder distance, catchment area, walking, bicycle, tram

I. INTRODUCTION

Pollution and congestion are important issues in the urban environment [1]. These can potentially be solved by multimodal transport, such as the bicycle-transit combination, which benefits from the flexible aspect of the bicycle and the wider spatial range of public transport [1,2]. Having access to both the bicycle and public transport, they can be used in one trip or substituted for each other, thus being a more robust alternative tot he car. With the bicycle as feeder mode, catchment areas can increase because of the larger distances that the cyclist is willing to bridge [3]. This benefits both individual travellers, because they have more options, allowing them to optimize their journey [3] and the network, as it can be coarser, more efficient and enabling a higher level of service [4]. This in turn attracts more travellers, again increasing efficiency [5].

Most transit operators consider a fixed 400m buffer as catchment area, although differences in catchment sizes have been observed for public transport stops of the same mode [6]. Therefore, a more informative way to describe catchment areas is the distance-decay function [7], which is defined as a way to measure the impedance to travel and shows the distribution of distances travelled to a stop [8].

Literature on the sizes of catchment areas has been present for a longer time, often focused on the bus, where median walking catchment sizes vary from 214-402 m [6] to 393-760 m [5]. Quantitative research about the factors that influence the size of catchment areas is limited. [9] found several factors affecting the catchment area but focused on heavy railway stations. No research has yet been conducted on catchment areas for tram stops. And although the bicycle-transit combination has grown in popularity, less knowledge is available about the bicycle as a feeder mode compared to walking [10]. The influences on cycling catchment areas are especially important to know in urban areas, where more competition is present between cycling and transit for single trips, but where they can complement each other at the total trip level [1,11].

Therefore, the objective of this paper is to assess which factors affect feeder distance and feeder mode choice of the tram. Data are collected using an on-board revealed preference survey among tram travellers in The Hague, The Netherlands. The data are used to test which factors affect feeder distance and feeder mode choice. Both bivariate and multivariate analyses (logistic regression) are applied to quantify the impacts. In addition, a qualitative analysis explores the motives of the tram travellers for using a stop further away than the nearest stop and the reasons for choosing the bicycle as a feeder mode. The outcomes of this paper can be used as input for multi-modal transport models where bicycle and public transport are integrated.

The remainder of this paper is organized as follows. Section 2 describes the methods applied in this research. In section 3 the results are presented. Section 4 discusses these results and finally in section 5 the conclusions and recommendations are given.

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II. METHODS

A. Data Gathering

To gain insights into the factors affecting the catchment area of cyclists and pedestrians, a theoretical framework has been developed. It contains four clusters of factors: user characteristics, transport factors, built environment factors and context factors. The influence of these factors is assessed for both feeder distance and feeder mode choice. A more detailed description of the theoretical framework can be found in [12].

Data are collected through a revealed preference survey, which was executed on-board four different tram lines in The Hague, the third largest city in the Netherlands with about 530,000 inhabitants [13]. Respondents were intercepted while travelling, which makes for more accurate, reliable and detailed results. Respondents were asked to fill out a two-sided A4 sheet, with questions about the respondent's journey from door to door (origin, first stop, last stop and destination, including transfer points), their travel options, travel habits, and socio-demographic characteristics. Furthermore, they were questioned about reasons for choosing certain options. Six consecutive days in April 2018 (a week with no extreme weather conditions or tram disruptions) were used to gather a total of 629 useful returned surveys. These resulted in 713 feeder distances, both access and egress, for which precise OD locations (six-digit postal codes or addresses) and street network distances were provided. For a more detailed description of the survey, see [12].

B. Model estimation

Bivariate statistical tests are used to determine which factors should be included in the multivariate analysis. To assess interrelations between the factors influencing both feeder distance and feeder mode choice, two multivariate regression models are estimated. These investigate the effects of the factors simultaneously.

For the feeder distance model, although it concerns a continuous scale, multiple linear regression is not suitable, because the residuals of the data follow a non-normal distribution, thus violating one of the conditions [14]. Therefore, a logistic regression model for feeder distance is estimated. The distance classes in the model are determined by testing various models with three or two distance classes. The models with three distance classes showed insufficient variation between the classes. Therefore, a model with two distance classes is used, where a 500 m cut off point is deemed to fit the data best. These distance classes for feeder distance also better represent the travellers' choices for either the nearest stop or a stop further away.For feeder mode choice, the outcome is binary (either walking or cycling), thus logistic regression is used as well. In addition to the quantitative analysis, a qualitative analysis is performed,providing insights into the motives behind stop and feeder mode choice.

III. RESULTS

A. Feeder distance

The median overall feeder distance for the tram stops is 400 m, consisting of walking (median of 380 m) and cycling (median of 1025 m), see Table 1 and Figure 1. This means that exactly half of the respondents in the The Hague survey travel further than the fixed buffer area of 400 m that many transit operators consider in network planning and ridership studies, something which was noted by [15] as well. When comparing the median walking distances with the findings of [5], who examined bus feeder distances in the Amsterdam region, it can be noticed that the median feeder walking distances in The Hague are substantially shorter (380 m instead of 393-760 m). On the other hand, in comparison with Sydney [15], the The Hague median walking distance is slightly higher (380 m instead of 364 m). The median cycling feeder distances in The Hague are considerably higher than those from bus services in Atlanta (904 m) and the Twin Cities (844 m) [10], which might be because the tram is considered higher in quality than bus.

TABLE I. OVERALL FEEDER DISTANCE VALUES (IN METERS)

	N	*min*	*max*	*median*	*mean*
Walking	657	10	2470	380	466
Cycling	56	80	3170	1025	1159
Total	713	10	3170	400	521

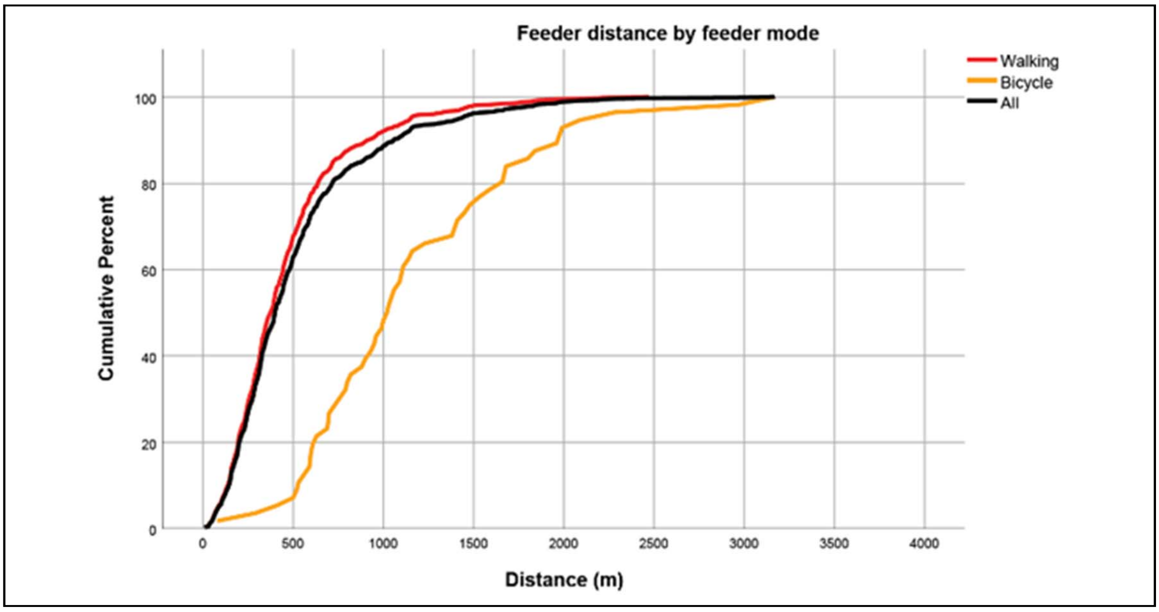

Fig. 1. Distance-decay functions of feeder distance, by feeder mode

B. Model results

Table II shows the results of the logistic regression model for feeder distance. For each variable the categories are compared with its base category to assess the probability of belonging to the distance class of >500 m (compared with >500 m). For continuous variables the effect is shown for the increase by one unit. Only feeder mode and transit stop density are significant: a high tram stop density and walking as feeder mode both decrease the probability of bridging a longer feeder distance than 500m.

Similarly, in the logistic regression model for feeder mode choice (Table III), the probability of belonging to either the walking or cycling class is assessed. In the feeder mode choice model only frequency of cycling, feeder distance, transit stop density and home-based versus activity-based are significant. A low frequency of cycling, a short feeder distance and an activity-based access/egress trip decrease the probability of choosing the bicycle as feeder mode.

C. Qualitative analysis

The motives for choosing a stop further away are mostly related with the quality of the transit service and comfort matters, where ‘avoiding a transfer’ is named most often (Figure 2). In [9] similar results are found. When asked which out of three options (avoid a transfer, have more options and bicycle parking facilities) would tempt travellers to choose a stop further away, most do this to avoid a transfer or having more options to reach their destination. However, a large share of travellers state that they always choose the nearest stop (Figure 3). Respondents that sometimes cycle to the stop were less likely to state that they would always choose the nearest stop compared with all respondents (Figure 4). This indicates that they are more inclined to travel further to a stop that suits them better.

The percentage of bicycle-tram users among the respondents is almost 16%. By asking the motives for not cycling to or from the tram stop, three barriers for choosing the bicycle as feeder mode have been identified: no bicycle available, insufficient bicycle parking places and unsafe bicycle parking places (Figure 5).

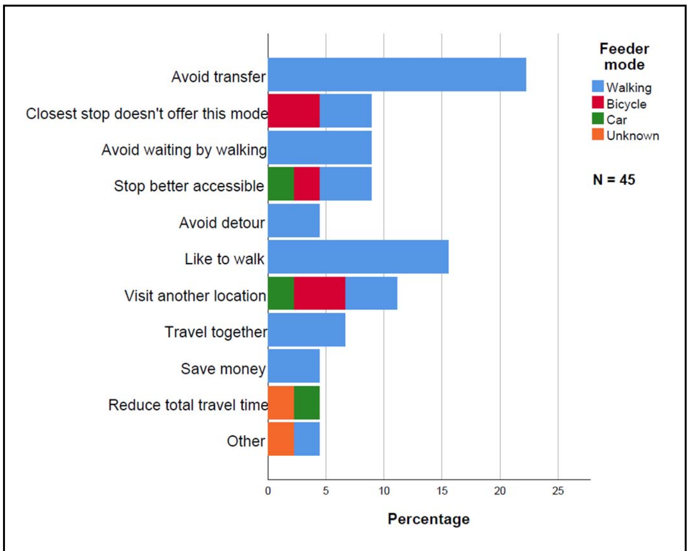

Fig. 2. Motives for choosing a stop further away, as mentioned by the respondents.

TABLE II. LOGISTIC REGRESSION MODEL FOR FEEDER DISTANCE: A DISTANCE OF MORE THAN 500M IS COMPARED WITH THE BASE (A DISTANCE OF 500M OR LOWER)

Variable	*Category*	*B*	*Sig.*	*Exp(B)*
Constant		2.575	**0.000*****	13.136
Feeder mode	*Base: walking* Cycling	2.438	**0.000*****	11.453
Frequency at the stop	*Base: low* Medium High	-0.693 -0.043	0.186 0.930	0.500 0.958
Directness of the line	*Base: direct* Inbetween Covering	-0.412 0.192	0.213 0.446	0.662 1.212
Amount of tram stops within 400m	*Base: 0 stops* 1 stop 2 stops 3 stops 4 or more stops	-2.996 -3.533 -3.688 -3.557	**0.000***** **0.000***** **0.000***** **0.000*****	0.050 0.029 0.025 0.029

TABLE III. LOGISTIC REGRESSION MODEL FOR FEEDER MODE. CHOOSING THE BICYCLE IS COMPARED WITH THE BASE (WALKING)

Variable	*Category*	*B*	*Sig.*	*Exp(B)*
Constant		-1.944	0.201	0.143
Feeder distance		0.002	**0.000*****	1.002
Age		-0.030	0.130	0.970
Transit captivity	*Base: other options available* No other options available	0.186	0.756	1.204
Frequency of cycling	*Base: 4-7 days/ week* 1-3 days/week 1-3 days per month Less than 11 days/year	-0.924 -2.396 -3.181	0.067 **0.035*** **0.004****	0.397 0.091 0.042
Trip purpose	*Base: working* School/internship Leisure/sport Shopping/groceries Visiting family/friends Other	0.218 -0.694 -0.713 -0.453 -3.288	0.727 0.415 0.428 0.562 0.267	1.243 0.499 0.490 0.636 0.040
Home-based/activity-based	*Base: home-based* Activity-based	-1.299	**0.012***	0.273
Bicycle parking at stop	*Base: not available* Available	-0.153	0.798	0.858
Frequency at the stop	*Base: low* Medium High	0.949 1.068	0.421 0.318	2.583 2.911
Directnes of the line	*Base: direct* Inbetween Covering	0.320 0.423	0.676 0.566	1.377 1.527
Amount of tram stops within 400m	*Base: 0 stops* 1 stop 2 stops 3 or more stops	-2.196 -1.348 -1.389	**0.010*** 0.061 0.074	0.111 0.260 0.249

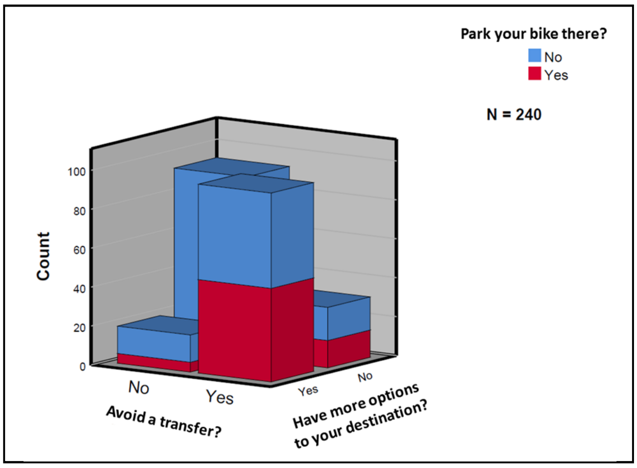

Fig. 3. All respondents: "Would you have chosen for a boarding stop further away if you could…?"

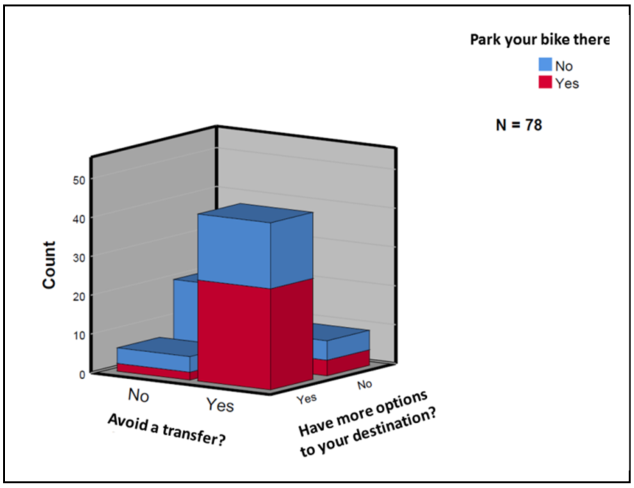

Fig. 4. Respondents who sometimes cycle to the stop: "Would you have chosen for a boarding stop further away if you could…?"

IV. Discussion

The results indicate that user characteristics do not significantly influence both feeder distance and feeder mode choice. However, [17] found that these factors are not relevant for cycling as a main mode. So, it appears that, for cycling as feeder mode, socio-economic factors are also not as influential as for cycling as main mode.

In contrast with literature expectations, trip purpose is not significant when tested in both logistic regression models. It is possible that the effect is eliminated because of insufficient variation in the surveyed lines: other line characteristics, e.g. directness or frequency, might interfere with the effect of trip purpose.

Several studies discuss the effect of high-quality transit: it supposedly leads to longer feeder distances [5,6,17,18,19], and the choice for the bicycle as a feeder mode [2,5,15,9]. However, frequency at the stop and directness of the line have produced remarkable results in this research. In contrast with expectations, the lowest frequency category and the 'in-between' directness category result in the longest feeder distances. This may be explained by how they are defined: frequency is measured as a cumulative value for all lines at the stop, while the frequency that is relevant for a specific trip might be more appropriate. Directness is defined as a combination of several other service quality aspects, so the combination of those separate effects may lead to remarkable results. Another explanation is that service factors are especially important between modes, instead of within modes.

Amount of transfers could not be tested for its relation with feeder distance, because of errors in the logistic regression model. However, it is still expected to be an important factor for feeder distance, because in the qualitative analysis it was considered an important motive for choosing a stop further away.

Lastly, a disadvantage of on-board surveys is that short-distance travelers may have insufficient time to complete the survey, and are therefore likely to be underrepresented. This may influence the results.

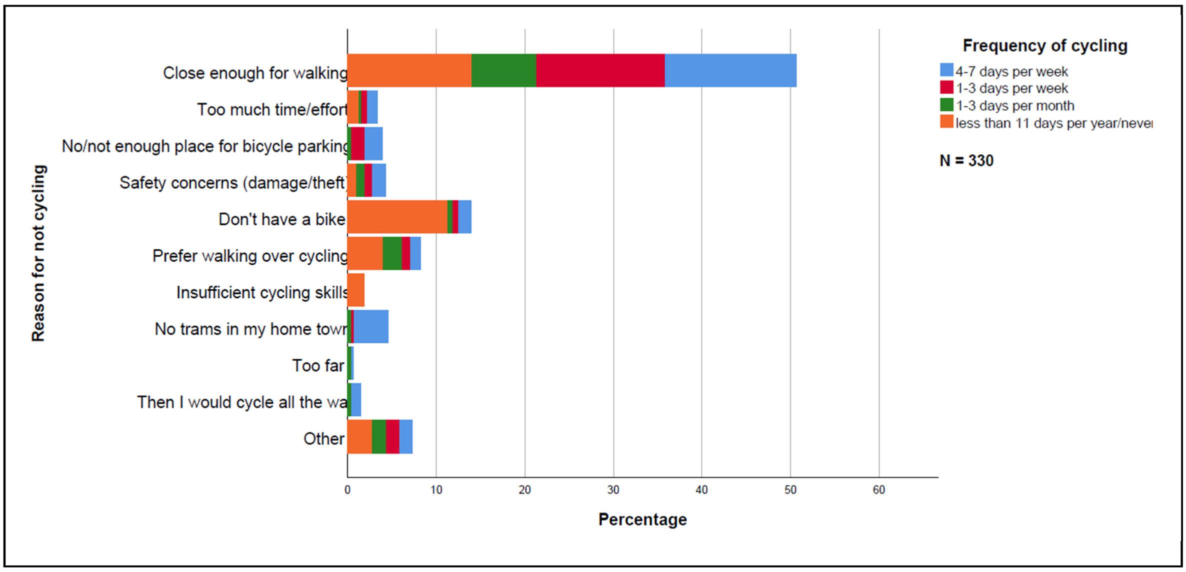

Fig. 5. Motives for not using the bicycle-transit combination, as mentioned by the respondents

V. Conclusions

This paper assesses which factors influence feeder distance and feeder mode choice, by analysing survey data from tram travellers in The Hague, The Netherlands. The outcomes of this paper can be used as input for multi-modal transport models where bicycles and public transport are integrated. When these predict ridership, feeder modes and feeder distances, tram systems can be better designed.

The main findings are as follows: Feeder mode and tram stop density are the most important factors that influence feeder distance. For feeder mode choice, also cycling habits and bicycle availability are important. The median overall feeder distance is 400 m, for walking it is 380 m and for cycling 1025 m. Three barriers for the bicycle-tram combination can be defined: no bicycle available, insufficient bicycle parking places and unsafe bicycle parking places. Lastly, tram travellers that sometimes use the bicycle-tram combination are more inclined to travel further to a stop that suits them better.

Transit operators are advised to redesign their network by mapping the found distance-decay functions onto the network, because overlap in catchment area makes the network inefficient. They should also encourage the bicycle-tram combination to increase the competing position of the tram, by addressing the three found barriers for cycling. A solution for the 'no bicycle available' barrier, which is also regarded as an essential feature in the bicycle-transit combination [13], could be to provide bicycle sharing schemes at tram stops. 'insufficient bicycle parking spaces' can be resolved by providing more parking facilities at the stop. Lastly, bicycle lockers or security cameras could make the bicycle parking spaces safer. When these barriers are removed, the amount of tram travellers that sometimes use the bicycle as a feeder mode could potentially rise from 21.7% to 37.5% of tram travellers, based on the sample from this research.

This research has not yet provided detailed knowledge on the *combined* choice for a stop and a feeder mode. Therefore, it is recommended that with the data generated during the survey, a joint choice model is estimated. With this, it can be established if the bicycle is indeed used as a feeder mode in order to avoid a transfer. Furthermore, the sensitivity of travellers for distance can be discovered.

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