PASSENGER ARRIVAL RATES AT PUBLIC TRANSPORT STATIONS

Marco Luethi (corresponding author), Ulrich Weidmann, Andrew Nash
Institute for Transport Planning and Systems
ETH Zurich
Switzerland

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Telephone: +41 44 633-2415
Fax: +41 44 633-1057
E-Mail: luethi@ivt.baug.ethz.ch
http://www.ivt.ethz.ch/oev/index_EN

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ABSTRACT
The amount of time spent waiting at a public transport station is a key element in a passenger's assessment of service quality and in mode choice decisions. Many transport models estimate the average wait time is half the headway for small headways and use a maximum waiting time for headways over a given value. The assumption is that at small headways passengers do not bother to consult schedules since vehicles arrive frequently; therefore these passengers arrive regularly at the station. In contrast, at longer headways passengers do consult schedules to reduce their waiting time; these passengers arrive clustered around the departure time. This research evaluated the influence of headway and other factors on passenger arrival rates at public transport stations based on data collected at 28 stations in Zurich's public transport network. It found that even at 5-minute headways, some passengers consulted schedules and did not arrive randomly at the station. This finding is interesting since 5-minutes is much lower than many models assume, therefore these models may be overstating passenger wait time. The research also found time-of-day and reliability had an important influence on passenger arrival rates. The research proposes a model for passenger arrival rates at stations that combines a uniform distribution with a shifted Johnson S_B distribution.

PASSENGER ARRIVAL RATES AT PUBLIC TRANSPORT STATIONS

1. INTRODUCTION

Passenger arrival rates at public transport stations are important for two main reasons. First, passenger arrival rates determine passenger waiting time which is an important factor in the attractiveness of public transport. Second, the passenger arrival distribution impacts public transport network stability; specifically, large variations in passenger arrivals at stops can create schedule instability by delaying transit vehicles. Public transport headway has been found to be one of the most important influences on passenger arrival rates and therefore the goal of this research project was to study the impact of headway on passenger arrival rates especially as several previous studies are relatively old.

Passenger arrival rates at stations can be described in terms of distribution curves. These curves plot the cumulative arrival of all passengers at the station. They can be used for travel models and microscopic simulations as well as an input for the vehicle dispatching process (to increase schedule stability). Two basic types of distributions are utilized: macroscopic distributions describe daily variations whereas microscopic distributions describe the variation between two consecutive service departures. This research focuses on microscopic distributions.

New information technology and consumer electronics have significantly increased a passenger's ability to obtain schedule information shortly before beginning travel. This should have an impact on passenger arrival patterns and the use of public transport. (*1*) (*2*) (*3*) These new influences as well as changing behavior patterns and habits since the earlier research, suggest that basic research on passenger arrival patterns should be pursued. This research can provide important data for both public transport operations management (simulation) and planning (modeling).

The research project consisted of collecting data on passenger arrivals at stations with different public transport frequencies. Additionally, passengers were surveyed regarding their impressions of service qualities (reliability) and their travel purpose.

Section 2 of the paper presents a review of earlier research. Section 3 describes the key factors influencing passenger arrivals at stations. Section 4 describes the data collection and analysis process. Section 5 summarizes study results and describes a passenger arrival distribution model, and Section 6 presents conclusions and recommendations.

2. LITERATURE REVIEW

Several different research projects were completed in Europe (circa 1970s) that considered passenger arrival and median wait times with respect to public transport headway. The studies showed a wide variation in median wait times and arrival patterns. (*4*) (*5*) (*6*) (*7*) (*8*)

The studies all showed that passengers do not arrive randomly at stations when public transport service is operated with long headways (low frequencies). However, there was much variation between the studies in terms of the headway below which passengers arrived in a random pattern and in their proposed models for estimating the relationship between wait time and headway as shown in Table 1. The studies also developed different models to describe the arrival patterns of passengers at stations.

The Braendli and Mueller study (8) proposed a passenger arrival model in which passengers are divided into two types:

- Passengers who do not know the timetable (schedule-independent) and thus arrive randomly at the station; or
- Passengers who know the departure time of the next trip (schedule-dependent).

The study offered many reasons why even schedule-dependent passengers (people who know the schedule) do not arrive at stations simultaneously with the arriving public transportation vehicle. Hence, this study focused on dividing passengers into schedule-dependent and schedule-independent groups, and on describing the distribution curves of passenger arrivals with respect to public transit headways at stations.

Study/City	Minimum Headway with Non-Random Arrival Pattern	Model Proposed for Relationship between Wait Time and Headway
Weber, Stuttgart, 1966	About 7 minutes	-
O'Flaherty, Leeds, 1970	5 minutes (Peak Periods) 12 minutes (Off Peak Periods)	Linear
Seddon, Manchester, 1974	7.5 minutes	quadratic
Jolliffe, London, 1975	12 minutes	linear
Braendli, Zurich, 1981	6 minutes (Peak Periods)	piecewise-linear

TABLE 1: Passenger arrival distribution findings

The Jolliffe and Hutchins study (7) proposed a model, in which passengers are divided into three categories:

- Passengers *q* whose arrival time is causally coincidental with the bus;
- Passengers *p (1 - q)* who arrive at the optimal time; and
- Passengers *(1 – p) (1 – q)* who arrive at random.

They found, that *p* increased with the service headway and was also larger for peak-hour observations. No relationships were observed for *q*, so a constant value of 0.16 was assumed as appropriate based on the measured observations.

3. KEY FACTORS INFLUENCING PASSENGER ARRIVAL DISTRIBUTIONS

Public transport headway has been identified as the most important influence on passenger arrival distributions in the microscopic analysis. Headway represents the primary service characteristic for public transport and is also used to estimate median wait time in transportation models. The median wait time is generally estimated at half the headway for headways up to a given limit, and then as a fixed value.

Public transport passengers (those who are not transferring from another route) can be divided into two main groups: those who know the schedule and those who do not know the schedule. The schedule-independent passengers, since they do not know the schedule, cannot plan their arrivals so that they arrive at the station near the departure time, thus they must arrive randomly. Over long time periods, these passengers essentially arrive at the station at a constant rate.

The second group of passengers, the schedule-dependent, do know the scheduled departure time, however they also do not arrive at the station exactly at the scheduled departure time. This is due to daily variability in the passenger's access time, passengers providing themselves with a margin of safety (arriving at the station a bit early), uncertainty about the exact time, and knowledge of public transport reliability. Given these conditions, passengers cannot exactly arrive at the scheduled departure time, in extreme cases even passengers who know the schedule arrive as if they did not. Nevertheless, a large share of the schedule-dependent passengers can arrive close to the planned departure time.

The superposition of these two groups of passengers, those who do not know the schedule (who arrive in a uniform distribution), and those who do know the schedule (who arrive in a non-random pattern), can be used to create the arrival distribution curve for all passengers at a given station. This research concentrates on the following two important questions:

- What influence does headway have on schedule-dependent and schedule-independent passengers?
- How does the median waiting period and the share of schedule-dependent passengers change in relation to the different influence factors?

4. DATA COLLECTION

Two types of data were collected in this research. The first consisted of observing passenger arrivals at public transport stations and recording the passenger arrival time and the vehicle departure time. The second consisted of interviewing waiting passengers. In the passenger surveys, only three questions were asked so that the interviews could be completed quickly. This was important to ensure that people arriving shortly before the bus departure could be interviewed without missing their bus. While this allowed us to interview many passengers, unfortunately it was not possible to interview people arriving simultaneously with the bus. This problem and the fact that some passengers refused to be interviewed were taken into account in developing the results. Specifically, the analysis is based on the observations of the passenger arrival flows, the surveys were used to gain an insight into the personal behavior of public transport users.

Data was collected at 28 bus, tram and commuter rail stations in and around Zurich. These stations were served by scheduled public transit operating at headways in the range of 2.33 to 30 minutes (see Table 2). The selected stations were required to have the following qualities:

- The station must be served by a single route;
- The route must operate with a constant headway over a minimal period (60-90 minutes);
- There could be no alternate waiting areas near the station (e.g. coffee shop, display window);
- No transfer possibilities;
- The station could not be a route’s first or last station;
- The station could not be the location of an intermediate turn; and
- The station must be busy enough to obtain sufficient data.

Zurich’s center city is served by a dense and finely meshed public transportation network, where multiple routes serve stations. It would have been impossible to explicitly link passengers to their corresponding routes at these stations. Therefore, during the morning peak periods and midday observations were mainly made in residential areas on the edge of the city center. Evening peak period observations were made in areas with many workplaces.

The observations were made on weekdays during three different time periods: the morning peak (6:30am – 8:00am), the evening peak (4:30pm – 6:00pm) and off-peak hours (9:30am-11:30am and 1:30pm – 3:30pm), referred to as off-peak in this paper. Two-to-four different stations were observed for each headway during each time period.

An average of approximately 90 passenger arrivals were observed at each surveyed station for each time period. Measurements were only made once at a given station/time-period in order to insure that the same person was not observed twice (i.e. on two different days) and could therefore bias the data set.

Frequency (Trips/Hour)	AM Peak Period	Midday	PM Peak Period
18	- Zurich: Heuried - Zurich: Locherguet		- Zurich: Irchel
12	- Zurich: Bernoulli-Hauser - Zurich: Fischerweg		- Zurich: Fischerweg
10	- Zurich: Herdernstrasse - Zurich: Rontgenstrasse - Zurich: SBB Werkstatte		- Zurich: Letzibeck
9	- Zurich: Freihofstrasse - Zurich: Grimselstrasse - Zurich: Luegisland - Zurich: Probstei		- Zurich: Rentenanstalt - Zurich: Saalsporthalle
8		- Zurich: Chaletweg - Zurich: Fischerweg - Zurich: Freihofstrasse - Zurich: Grimselstrasse - Zurich: Saalsporthalle - Zurich: Waidspital	
6	- Dietikon: Gjuchstrasse - Zurich: Sihlweidstrasse	- Zurich: Sihlweidstrasse - Zurich: Marbachweg	- Zurich: Binz Center - Zurich: Giesshubel - Zurich: Sihlweidstrasse - Sood-Oberlaimbach
4	- Dietikon: Stelzenacker - Forch - Waltikon	- Dietikon: Gjuchstrasse - Oberengstringen: Paradies - Zurich: Binz Center	- Zurich: Zentrum Glatt
2	- Buchrain - Burghalden: Zweischurli - Hedingen		

TABLE 2: Data collection

5. EVALUATION RESULTS

This section presents key results of the analysis. It describes the influences of several factors, mainly service headway, on the median waiting time and the proportion of passengers who can be categorized as timetable-dependent.

In the discussion the term "*timetable-dependent*" refers to passengers who know the schedule and try to arrive at the station near the scheduled departure time; while the term "*timetable-independent*" refers to passengers who arrive at the station randomly with respect to departure time. The timetable-independent group consists of people who do not know the schedule and also a share of the people who do know the schedule but either consciously or for unknown reasons, behave like timetable-independents (i.e. arrive randomly at the station with respect to departure time).

Figure 1 illustrates the concept of classifying passengers according to the *timetable-independent* and *timetable-dependent*.

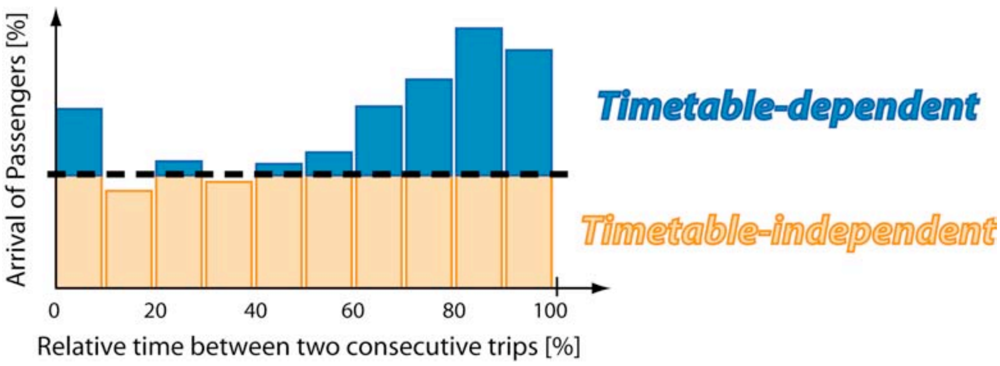

FIGURE 1: Passenger timetable dependency classification

Influence of Headway on Median Passenger Waiting Times

Since headway has been identified as the primary influence on passenger arrival rates at public transport stations, the first step in this research was to describe the influence of headway on the median waiting time of the passengers at stations.

Figure 2 plots median wait time versus headway during the peak period using data collected for this research. The dashed line represents the "waiting time is equal to half the headway" rule of thumb. As shown in Figure 2, the results, observed during the peak hours, from Zurich illustrate that the half of headway rule is generally accurate until a headway of about 5-minutes; at this point average wait times become essentially smaller than half of headway time for different service frequencies showing that passengers know the schedule. At headways of 10-to-15 minutes the "half the headway" rule is a quite poor estimate for average wait time.

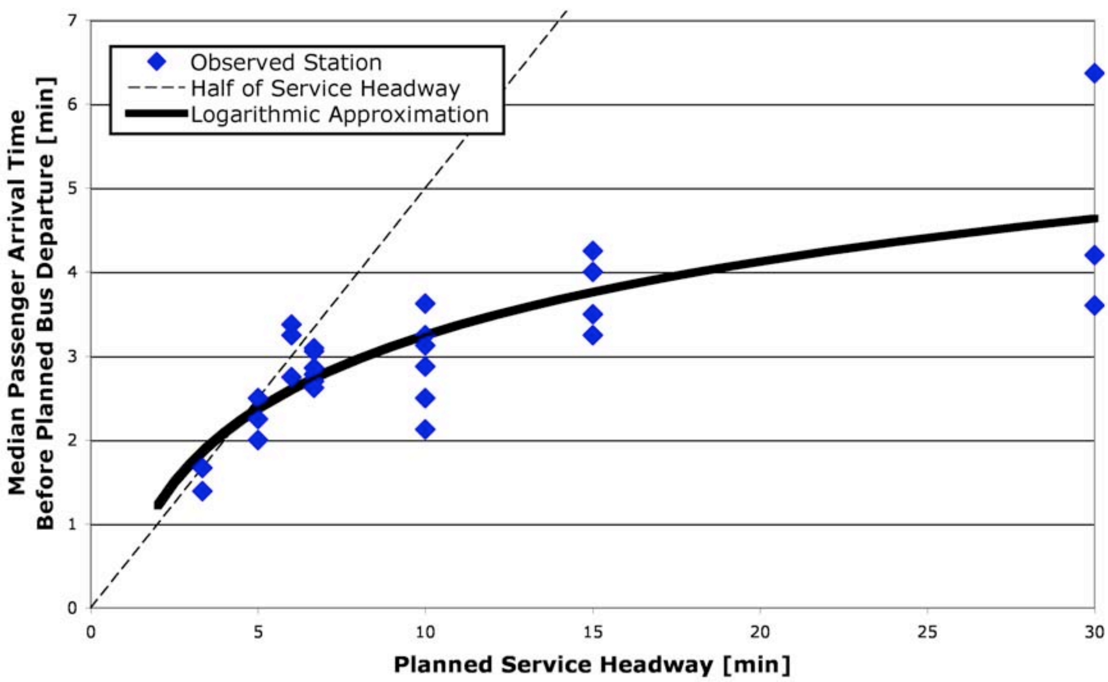

FIGURE 2: Median passenger waiting time versus headway for peak periods in Zurich

In contrast to previous studies in the 1970's where linear or quadratic models were applied, a logarithmic approximation fits much better for the new observations in Zurich. The behavior of passengers with very short but also for long headways is approximated much better with the logarithmic model compared to other possibilities.

Influence of Headway on Passenger Arrival Distribution

Next, the data were used to develop passenger arrival distribution and density curves. Figure 3 illustrates the density of passenger arrivals at stations for six different headways during the morning peak period. The influence of headway is clearly visible. It is also recognizable that at a headway of 5 minutes (300 seconds) a share of passengers appear to know the schedule and arrive at the stop quite near the departure time. This confirms the research by O'Flaherty and Mangan and differs from earlier investigations in Zurich (which found that passengers arrived based on the schedule starting at headways of 6-minutes).

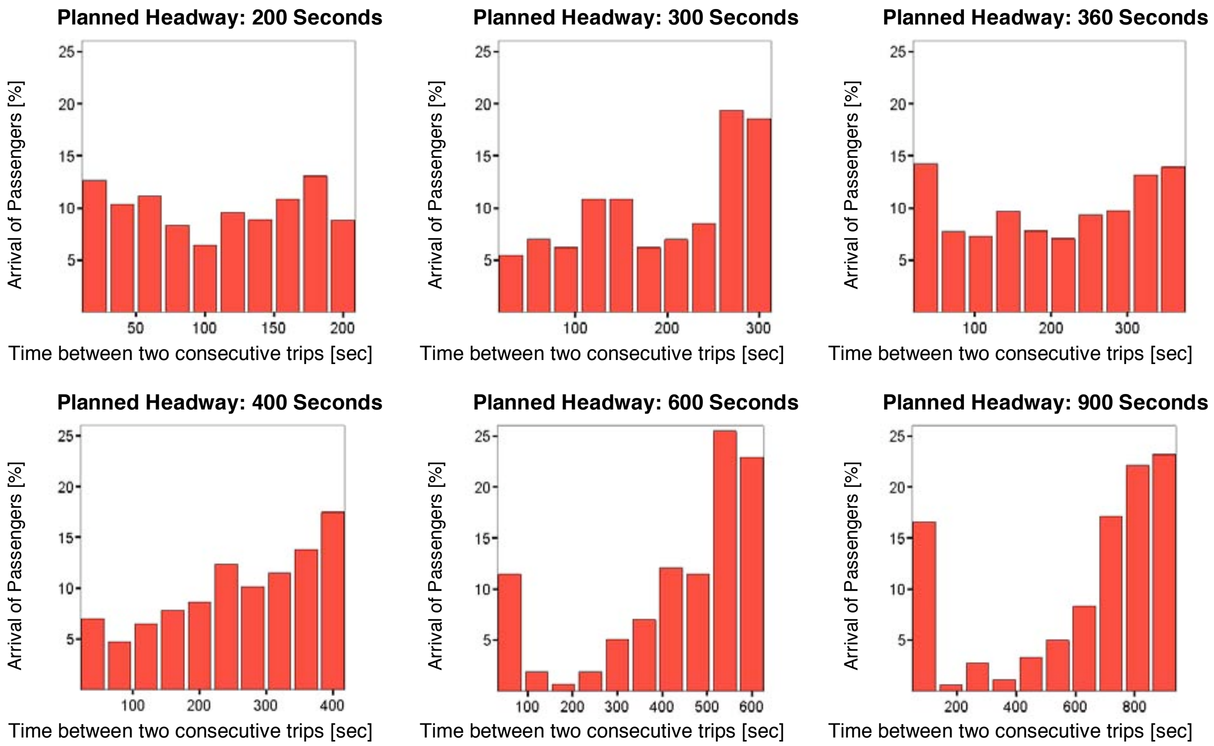

FIGURE 3: Temporal density of passenger arrivals at stops between the scheduled departure times for successive trips during the morning peak hour.

The density curves also show clearly the differentiation of timetable-dependent and timetable-independent passengers for the various headways. These observations, specifically those regarding the shape of the distribution curves and the proportion of timetable-independent passengers, can be used to describe a general model for the passenger arrival distribution. This model distribution would combine two model distributions: one for timetable-independent and the other for timetable-dependent passengers.

The density of *timetable-independent* passenger arrivals over time (between the scheduled departure times) can be modeled as a Uniform density *U(a,b)*

$$U(a,b): \quad f_{U(a,b)}(x) = \begin{cases} \dfrac{1}{b-a} & \text{if } \; a < x < b \\ 0 & \text{otherwise} \end{cases}$$

and the density of *timetable-dependent* passengers over time can be modeled as a Johnson S_B $JSB(a,b,\alpha_1,\alpha_2)$:

$$JSB(a,b,\alpha_1,\alpha_2): \quad f_{JSB(a,b,\alpha_1,\alpha_2)}(x) = \begin{cases} \dfrac{\alpha_2(b-a)}{(x-a)(b-x)\sqrt{2\pi}} e^{-0.5\left\{\alpha_1 + \alpha_2 \ln\left(\frac{x-a}{b-x}\right)\right\}^2} & \text{if } \; a < x < b \\ 0 & \text{otherwise} \end{cases}$$

The parameters $\alpha_1 \in (-\infty,\infty)$ and $\alpha_2 > 0$ describe the shape of the Johnson S_B density curve. They were estimated to fit the observed data in a best possible way. Distribution-Function-Differences plot and formal methods (e.g. Chi-Square Test) were used to evaluate the best-fitting model-parameters. The Johnson S_B function is closely related to the classical normal distribution and is skewed right for $\alpha_1 < 0$.

The distribution of the timetable-dependent passengers is shifted with the value δ_{ts} which mainly depends on the headway. The reason for this shift is that some passengers know very well the reliability and average delay of the public transit service and therefore they arrive regularly a short time after the scheduled departure time. The shifted Johnson S_B denisty $JSB_{sh}(a,b,\alpha_1,\alpha_2)$ is described as

$JSB_{sh}(a,b,\alpha_1,\alpha_2)$:

$$f_{JSB_{sh}(a,b,\alpha_1,\alpha_2)}(x) = \begin{cases} \dfrac{\alpha_2(b-a)}{(x+b-\delta_{ts}-a)(\delta_{ts}-x)\sqrt{2\pi}} e^{-0.5\left\{\alpha_1+\alpha_2 \ln\left(\frac{x+b-\delta_{ts}-a}{\delta_{ts}-x}\right)\right\}^2} & \text{if } a < x < \delta_{ts} \\ \dfrac{\alpha_2(b-a)}{(x-\delta_{ts}-a)(b+\delta_{ts}-x)\sqrt{2\pi}} e^{-0.5\left\{\alpha_1+\alpha_2 \ln\left(\frac{x-\delta_{ts}-a}{b+\delta_{ts}-x}\right)\right\}^2} & \text{if } \delta_{ts} < x < b \\ 0 & \text{otherwise} \end{cases}$$

with $0 < \delta_{ts} < b$.

The general boundaries with the range (a,b) can be substituted with 0 and the headway time t_{hw}. The proportion of passengers who arrive randomly at a station is defined as c_{si}.

Therefore, $c_{sd}=(1- c_{si})$ are schedule dependent. This results in the final, overall passenger arrival density $f_{pa}(x)$ which can be expressed as:

$$f_{pa}(x,\alpha_1,\alpha_2) = c_{sd} \cdot f_{U(0,t_{hw})} + c_{si} \cdot f_{JSB_{sh}(0,t_{hw},\alpha 1,\alpha 2)}$$

$$f_{pa}(x,\alpha_1,\alpha_2) = \begin{cases} \dfrac{c_{sd}}{t_{hw}} + \dfrac{c_{si}\alpha_2 t_{hw}}{(x+t_{hw}-\delta_{ts})(\delta_{ts}-x)\sqrt{2\pi}} e^{-0.5\left\{\alpha_1+\alpha_2 \ln\left(\frac{x+t_{hw}-\delta_{ts}}{\delta_{ts}-x}\right)\right\}^2} & \text{if } 0 < x < \delta_{ts} \\ \dfrac{c_{sd}}{t_{hw}} + \dfrac{c_{si}\alpha_2 t_{hw}}{(x-\delta_{ts})(t_{hw}+\delta_{ts}-x)\sqrt{2\pi}} e^{-0.5\left\{\alpha_1+\alpha_2 \ln\left(\frac{x-\delta_{ts}}{t_{hw}+\delta_{ts}-x}\right)\right\}^2} & \text{if } \delta_{ts} < x < t_{hw} \\ 0 & \text{otherwise} \end{cases}$$

Two examples visualizing the model using the superposition of uniform and Johnson S_B density are illustrated in Figure 4:

$t_{hw} = 10;\ c_{sd} = 0.15;\ \delta_{ts} = 0.8;\ \alpha_1 = -1.2;\ \alpha_2 = 1$ $t_{hw} = 6.33;\ c_{sd} = 0.7;\ \delta_{ts} = 0.2;\ \alpha_1 = -1;\ \alpha_2 = 1$

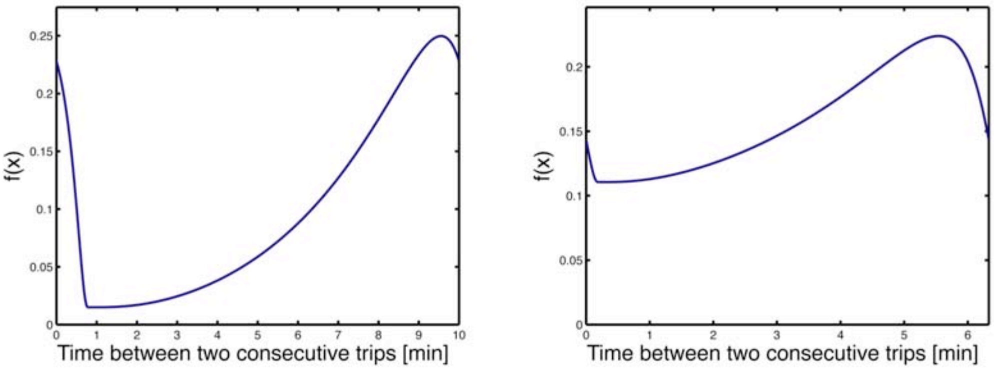

FIGURE 4: Passenger arrival models for varying headways using a superposition of Uniform and Johnson S_B density model.

Influence of Time-of-Day on Arrival Rates

The observed arrival rates of passengers at stations can be used to determine the share of passengers who are timetable-dependent and the share that are timetable-independent for a specified headway. This data can then be used to assess the share of passengers who "know the schedule" under different situations.

Figure 5 illustrates how the share of passengers who are timetable-dependent varies for the three main periods of the day: morning peak, off-peak and evening peak. As shown in Figure 5, there is a substantial difference in the share of passengers who know the schedule at different times of the day, especially between the peak periods and off-peak.

Not unexpectedly, the highest share of timetable-dependent people were observed during the morning peak, because many passengers are regular commuters who know the schedule. The amount of timetable-dependent passengers during the evening peak is slightly lower than in the morning peak because people experience less time pressure and often stop working at different times on different days. Finally, the share of timetable-dependent passengers during the midday is lowest because most passengers are not making regular trips at this time and therefore do not know the schedule. This finding suggests that efforts to help midday users obtain schedule information might help increase public transit demand.

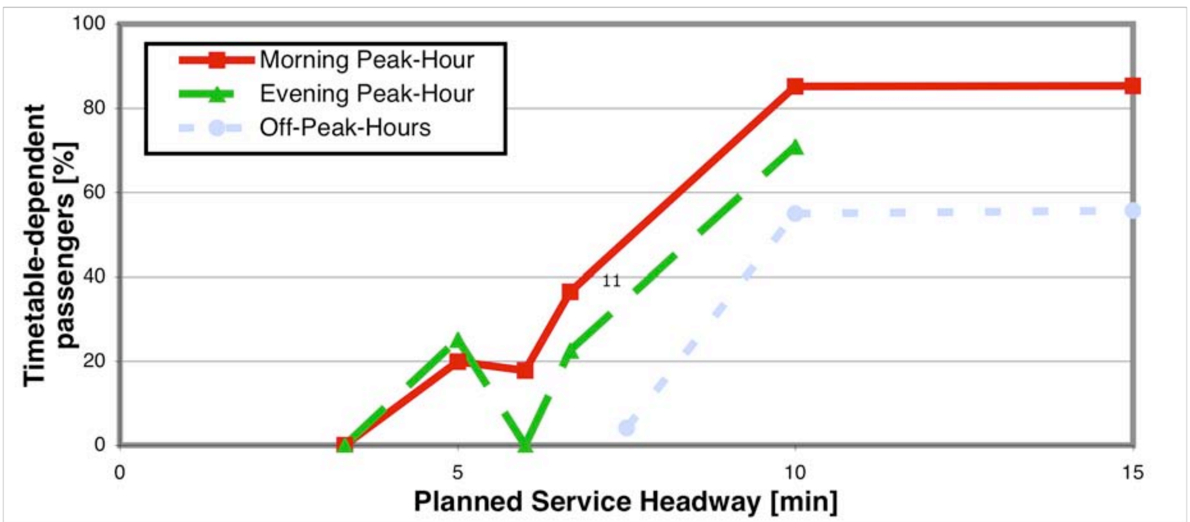

FIGURE 5: Portion of timetable-dependent passengers with respect to the time of day and headway.

Figure 5 also illustrates that the number of passengers who appear to know the schedule is noticeably higher for a 5-minute headway than for a 6-minute headway. This might be caused by the difficulty of memorizing 6-minute versus 5-minute intervals.

Another interesting finding illustrated in Figure 5 is the high percentage of passengers who are timetable dependent at a headway of 400-seconds (approximately 30% during the morning peak), a headway used extensively on Zurich's tram network. This is an interesting result since it is very hard for passengers to memorize this headway (corresponding to 9 vehicles per hour) although a considerable portion of Zurich passengers seem to have done so. This suggests an extremely frequent level of bus and tram use in peak periods.

Influence of Pubic Transport Reliability on Passenger Arrival Time

The fact that passengers arrive on schedule at stops even for routes with short headways shows that Zurich's public transport system operates with a high degree of reliability. In parallel with the observations of passenger arrivals at public transport stops, passengers were surveyed about their perception of reliability and whether they try to arrive at the stop at the scheduled departure time. The results of this survey, presented in Figure 6, show that (as should be expected) more people who perceive the daily delay of the services to be small arrive on-schedule at the station compared to passengers who perceive the daily delay to be larger.

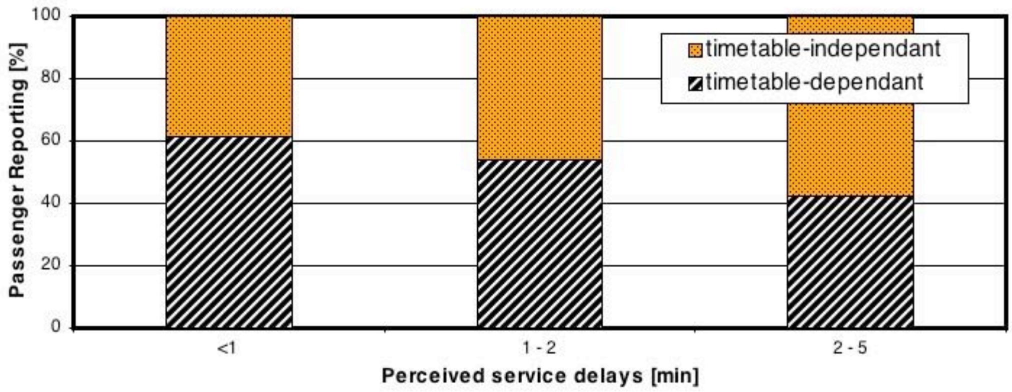

FIGURE 6: Influence of perceived reliability (on-time departure) on passenger timetable dependence (survey of stops with headway of 400 seconds during the morning peak period).

It is important that passengers perceive that public transport is reliable since much research has shown that passengers estimate the waiting period to be much longer than the actual waiting period (estimated waiting time increases exponentially) (*9*). Thus to make public transport attractive, it is important to operate it with well-known schedules as punctually as possible.

One interesting result of the survey was the finding that passengers think they know the schedule more than they really do. Specifically, the survey showed, that during the morning peak period for transit service with a headway of 400 seconds, 54% of all passengers said that they tried to arrive on schedule; however, the observations of actual appearance at the stop showed that only 31% arrived in a pattern that indicated that they are timetable-dependent. In this case therefore, 23% of passengers try to reach the station on schedule, but their behavior is not distinguishable from randomly arriving passengers.

Influence of Pubic Transport Reliability on Passenger Arrival Time

Figure 7 compares results of this research to the earlier studies. As shown, results of this research show a reduction in median wait time. Whether this is to due to better passenger information, improved reliability, higher value of time for passengers, or to other causes, cannot be judged conclusively.

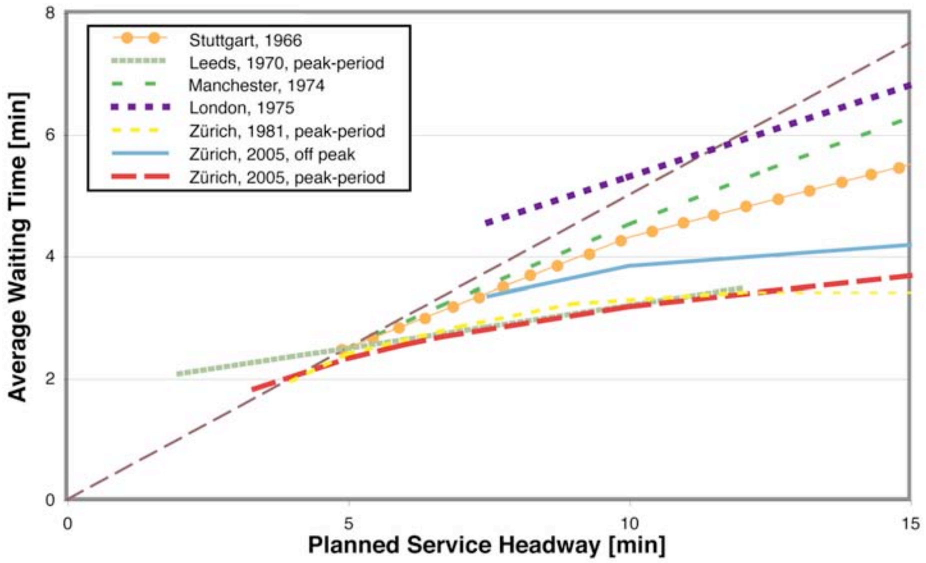

FIGURE 7: Study results compared to earlier research: relation of median wait time to headway.

6. CONCLUSIONS AND RECOMMENDATIONS

This research found that passengers begin to arrive at public transport stations near the scheduled departure times even with very short headways. This is especially true when passengers believe that public transport's on-time performance is good. The research also showed, that the median waiting time of passengers with respect to headway can be modeled with a logarithmic function. Similarly, the microscopic passenger arrival distribution, describing the variation and distribution pattern between two consecutive services, can be modeled as a superposition of a Uniform distribution (for the timetable-independent passengers) and a shifted Johnson S_B distribution (for the timetable-independent passengers).

The study investigated the influence of headway on passenger arrival rates in detail, however there are clearly many other factors that influence passenger arrival at public transport stations. Additional research is recommended to investigate the influence of factors including: route reliability, time of day, travel purpose, remember-ability of the schedule, location of station in network, station environment, access distance to station and previous activity (e.g. work, school). Similarly, it would be very interesting to compare these results to measurements for public transportation systems with a lower reliability than Zurich's.

Finally, ongoing development in information technology will change passenger behavior and their relationship with public transportation. The integration of online data with other applications, for example devices that present a visualization of actual train positions (*10*) or send a text message to a mobile phone with actual and delay relevant real-time timetable information (*11*), will help customers to optimize their travel and waiting times. These types of systems will improve the quality and attractiveness of public transportation systems and therefore should also be investigated in future research.

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