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Waiting Time Strategy for Public Transport Passengers

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To overcome future challenges in urban transport, it is crucial that transport models and cost benefit analyses provide a better approximation of real travel costs for public transport trips; however, it is challenging to exemplify public transport's generalized cost components. This paper focuses on waiting time as one component of generalized costs. Unlike other relevant components, waiting time is partly determined by an individual strategy. The open waiting time is also affected by line punctuality; delays prolong the actual waiting time unless the delay is normal and travelers have adjusted to this situation. It is quite common to use the assumption of random passenger arrivals at bus stops (as in the Norwegian regional transport model, RTM), to represent the total waiting time, both open and hidden. This study presents results from field registrations and surveys, as well as passengers' actual waiting times and their waiting time strategies. The registrations were completed during morning rush hour in low-frequency services and in residential areas. The results show that passengers plan their arrivals at bus stops, which implies lower waiting times than normally assumed in transport models. The results published here indicate how transport models could be developed to better deal with low-frequency public transport services.

1 Introduction

Large population growth in cities and environmental concerns across the world puts increasingly higher demands on public passenger transport systems. For instance, in several European cities, including the nine largest urban areas in Norway (Samferdselsdepartementet, 2012), there is a requirement that the number of public transport trips increase to achieve the greater aim of reducing the total number of car trips. To overcome the challenges associated with this increase, it is crucial that transport models provide a realistic approximation of actual travel costs for public transport trips. In low-frequency public transport services, which exist in most Norwegian cities (and other small and medium-sized cities worldwide), we expect that the waiting time normally assumed in transport models is much higher than what passengers experience in real life.

Representing the public transport service system is not straightforward, as discussed in Ortuzar and Willumsen (2004) and Nielsen (2000). Traditionally speaking, public transport trips have been broken down into time, cost and inconvenience components. Whereas each of the components have been linked to simplifications to codify both the service and assumptions linked to traveler assessments, in turn weighting the components together to form generalized cost (Abrantes and Wardman, 2011). While this paper concerns waiting times alone, other researchers have focused on how the models could represent the travelers' route choice (Liu et al, 2010, and Nielsen, 2000). Route choice among public transport passengers is also linked to onboard capacity issues (Raveau et al, 2014). A realistic route choice implies realistic passenger loads with respect to the model's various services, including the division between different modes of PT (Bovy and Hoogendoorn-Lanser, 2005), making it possible to estimate required total passenger capacity and crowding. Others have focused on the assessment of various PT components, and which components to include (Fosgerau et al, 2007).

Our research focuses on waiting time as one of the components. We have avoided route choice issues by choosing bus stops in residential areas, which are served by only one bus route, and with no other bus stops nearby. Our research thereby focuses on waiting time for passengers who have already chosen public transport and with no optional route choices. Unlike several of the other components, waiting time is not a variable solely determined by the service; rather, it is chosen by the traveler based on the service – thus, the traveler has an arrival strategy to the bus stop. Naturally, this strategy is linked to the headway. If the service is frequent, e.g. with five-minute headways, the arrival strategy includes merely going whenever you need to and taking the first convenient bus, because passengers cannot effectively reduce their open waiting time by means of employing clever arrival strategies (Liu et al, 2010). If the service is less frequent, this strategy leads to high average waiting times. The most common action is to check the departure times, pick one and arrive accordingly at the bus stop, perhaps a few minutes early in case the bus is a little early, your watch is not exactly on time or something unexpected happens. An arrival strategy is likely to differ between low and high frequency services; thus, it is interesting to reveal actual waiting times in low-frequency services.

To provide reliable estimates of travel demand, the transport models' data input must be of high quality. The demand calculations are based on the inconvenience of journeys between A and B using every available means of transport. The inconveniences are then converted into a common cost unit, and the sum is known as the generalized travel cost (GC). The calculated GC for a trip by public transport consists of the inconveniences of walking to, between and from bus stops, representing the access and egress time, time on board the vehicle, waiting time and fares (Balcombe et al, 2004).

Data input used in the transport models regarding the duration of each stage of the trip, except for the first waiting time, probably provides a good representation of the real travel time, though simplifications are made in all components (problems with each are discussed in Ortůzar & Willumsen, 2004). The data input for the waiting time that occurs at the start of the trip, before passengers board any vehicle, is not based on any form of registration of actual waiting times (Hjorthol et al., 2014). Rather, it is solely based on the time between bus departures (headways). In addition, the modeled waiting time is based on an assumption of random passenger arrivals at the bus stops (Amin-Naseri and Baradaran, 2015). Based on this assumption, the average waiting time for all passengers is the statistical expected value equal to half the time between departures (W=h/2). This might be a good estimation of waiting time in high-frequency services; however, if passengers plan their arrival at the bus stop, the open waiting time (the duration of passengers' stay at the bus stop) is not a great deal longer at longer headways (Fosgerau et al, 2007). This implies that the open waiting time is considerably less than half the time between departures in low-frequency services.

Based on field studies carried out in Trondheim, Norway, we have investigated the open waiting time among public transport passengers. A survey was undertaken to follow up results from the passenger arrival registrations and gather more information as to how passengers plan their waiting time. Together, this data has given us more insight into public transport passengers' waiting time strategy. Based on this new knowledge, we have taken one step closer to determining more accurate approximations of reality in the transport models.

This paper will contribute with empirical evidence on observed waiting time in low-frequency public transport services. In addition, this will form a basis for further research on how to better deal with waiting time in the transport models, as the current literature on the strategy-part is sparse.

2 Method

2.1 Study design

In this study we aim to reveal passengers' actual waiting time in low-frequency public transport services. Most transport models use the assumption of uniform and random passenger arrivals at all public transport trips, even though this has been found to be valid only in high-frequency services (Seddon and Day, 1974, found in McLeod, 2007). Consequently, the transport models overestimate the waiting time in low-frequency services, which exist in most Norwegian cities. The goal of this study is to map out actual waiting times for public transport passengers travelling at different headways, and reveal if there is any correlation between different aspects of the waiting time strategy and the public transport service. To accomplish this, we have divided the waiting time into different elements, defining them as follows:

Open waiting time: The time passengers are at the bus stop waiting for the bus.

Hidden waiting time: Waiting time at the origin before travel begins. (In this study, we only look at the hidden waiting time at the start of the trip and not at the end.) This waiting time exists because public transport passengers cannot travel whenever they want.

Additional waiting time: The extra waiting time that occurs because of bus delays. The time between the scheduled and actual bus departure.

Waiting time: The entire waiting time, including the open, hidden and additional.

Preferred waiting time: The open waiting time that passengers have included in their travel plans.

Waiting time strategy: All possible means passengers can use to reduce their waiting time, including open, hidden, and additional.

Registered waiting time: The open waiting time registered in the field study.

Actual waiting time: Refers to the waiting time observed in this study, including either open waiting time or the entire waiting time.

This study only deals with the waiting time passengers experience at the start of the trip before they board any vehicles. The study is aimed at frequent public transport users (commuters), and trips starting at home. This is because frequent public transport users are more likely to have a strategy for dealing with their waiting time, or at least a plan and routine for when to start their journey. In addition, it is expected that such a strategy is more likely to be used when the trip starts at home in the morning, than at other public transport trips.

We used two types of data collection. Initially, the open waiting time of 1145 passengers was registered during the morning rush-hour traffic, in February 2016. The registrations were completed at 24 different bus stops in residential areas a few kilometers outside the city center of Trondheim, at 16 different days, and each session lasted approximately two hours. The number of registered bus routes was seven, of which two were registered along both sides of the city center, and one was registered at two different headways. We registered the exact time of every passenger's arrival at the bus stop and the exact departure time of every bus. The open waiting time for each passenger is found as the time between their arrival and the departure time of the bus they boarded. This means that boarding time is included in the open waiting time.

Secondly, 109 public transport passengers answered a survey about their waiting time strategy while waiting at the bus stops. Each bus stop was surveyed only once at the same time period to avoid double-counting.

2.2 Arrival registrations

Where, when and how the arrival registration was conducted was meticulously determined in order that it would be in accordance with the study's objectives. Registrations were conducted during morning rush hour traffic in residential areas to seek out journeys starting at home, and having a majority of passengers who are frequent public transport users, as they are more likely to have a waiting time strategy. Registrations were conducted at 10-, 15-, and 20-minute headways to discover if both the passenger arrival distribution and passengers' waiting time strategy are dependent on the headway. All bus stops where the registrations took place had to satisfy the following requirements:

1. Served by only one bus route.
2. The bus route operates on a fixed schedule, with the same number of minutes between all departures during the registration period.
3. Located in a residential area.
4. There are no bus stops nearby serviced by other routes.
5. There are no nearby grocery stores, shopping malls, schools or kindergartens.

When taken together, these requirements contribute to maximizing the probability that the passengers' initial waiting time will be registered (they have not done any errand in advance), they will have started their trip at home, and they will have planned their journey from exactly this stop.

All passengers who arrived at the chosen bus stop were registered at their exact time of arrival, and the same was done for the buses' departure. The definition of when a passenger arrives at the bus stop is not unambiguous. Indeed, in this study the arrival was defined by the point in time at which the passenger stopped walking – and started waiting – independent of the location where this took place. All registrations started and ended with a bus departure to avoid an over-representation of passengers arriving early and late. The registrations were conducted by using a self-designed application for smartphones, where the time stamp for all passengers and buses were saved in a file.

When processing the collected data, the duration of each individual open waiting time was determined by calculating the time between the time of passenger arrival and bus departure time. When information from the timetable was included, the data also showed at what time passengers arrived prior to the planned bus departure time in addition to each vehicle's delay.

2.3 Survey design and collecting responses

The survey is designed so that we only gather information about the trip every passenger makes most frequent. We chose this to allow the passengers to give us a high degree of detail in their answers regarding both their time usage and waiting time strategy. We asked questions about the passenger, travel purpose, headway, and instances of bus delays for the particular journey. The most questions concern the passenger's individual waiting time strategy and time usages on the way to and on the bus stop. This includes questions like; *Are you familiar with the timetable? Are you planning the time when your trip starts at home? How long before bus departure do you prefer to arrive at the bus stop? How do you deal with delays?* To keep the questions simple, no questions regarding time costs were asked. However, different evaluations of the various waiting time phases are of great interest; hence, the respondents were given a scenario where they chose which part of the journey they would prefer to shorten and increase by one minute. The survey is designed as a multiple choice, except for questions regarding time use where the respondents gave their answers in minutes and seconds.

The survey is conducted online, and the respondents should be able to answer on their own through using their cell phone. The main reason for this is to allow the passengers to complete the survey while either waiting at the bus stop or sitting on the bus – places they normally do not have much else to do. This will likely result in more responses and having respondents give accurate answers. Online surveys might also exclude a certain number of potential respondents. However, given the fact that there is a great deal of internet use on cell phones at public places in Norway, the number of excluded passengers was for this reason expected to be minor.

The responses were collected in Trondheim during morning rush hour at various bus stops meeting every requirement defined above. Thus, the survey answers and registrations have the same validity and are comparable. Most responses were collected at bus stops with high passenger numbers to get as many respondents as possible during a brief time period. Hence, there may be an under-representation of passengers traveling at larger headways.

The initial intention was to ask all arriving passengers; however, this proved to be impossible. For example, some passengers arrived just in time before their bus departed, so there was no time to ask them questions. Hence, there might be an under-representation of passengers aiming for zero open waiting time. Other situations such as crowding, and passengers who did not want to answer the survey resulted in an overall response rate of around 40%.

3 Results

3.1 Open waiting time

One of the main goals is to map out the duration of passengers' open waiting time, which in this study includes the length of passengers' waits at the bus stop from when they arrive at the platform until the bus departs. Knowing the exact duration of the open waiting time makes a considerable contribution to producing a better approximation of the real travel costs for public transport trips. Seeing how the arrival distribution varies with different headways enables the models to calculate more accurate travel costs for trips undertaken at any public transport service.

The arrival distributions found at the three different headways are shown as histograms in figure 1 and as cumulative distribution functions in figure 2, having the open waiting time located along the x-axis. Table 1 summarizes the differences in open waiting time at the different headways.

Table 1: The observed open waiting time at different headways. All numbers in [mm:ss].

Headway	N	Average open waiting time	Median	Standard deviation
10 minutes	494	03:12 (0,32*h)	02:39	02:26
15 minutes	457	04:25 (0,29*h)	03:33	03:07
20 minutes	194	05:33 (0,28*h)	04:23	04:28

The large standard deviation shows (see figure 1) that the passenger arrivals is widely spread. This indicates that many different strategies are used, as well as irregularities in bus arrivals.

Figure 1: Arrival distributions at 10-, 15- and 20-minute headways. Number of passenger arrivals pr. minute.

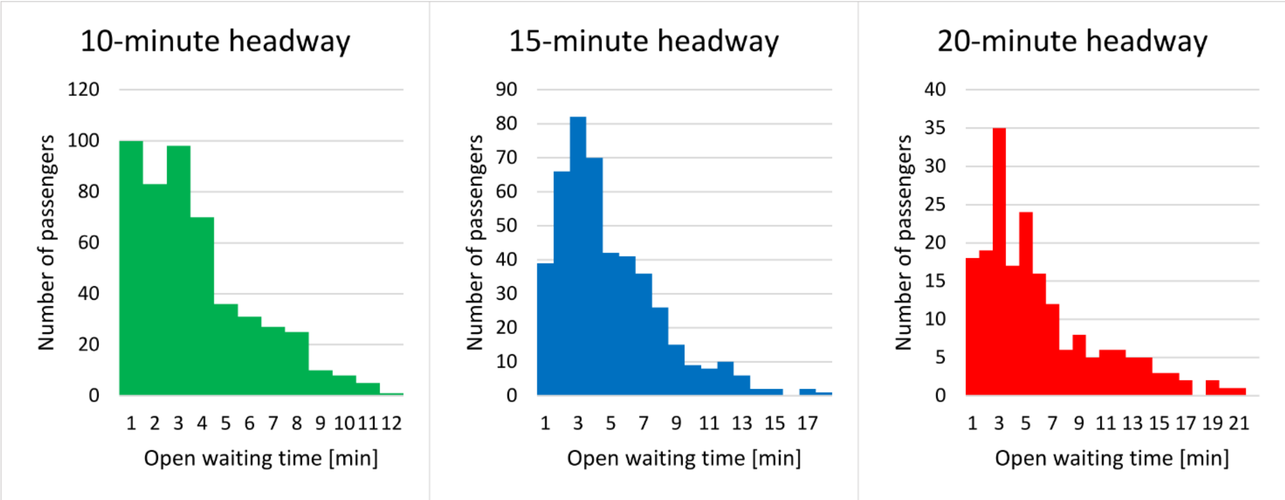


Figure 2: Cumulative arrival distribution at 10-, 15-, and 20-minute headways.

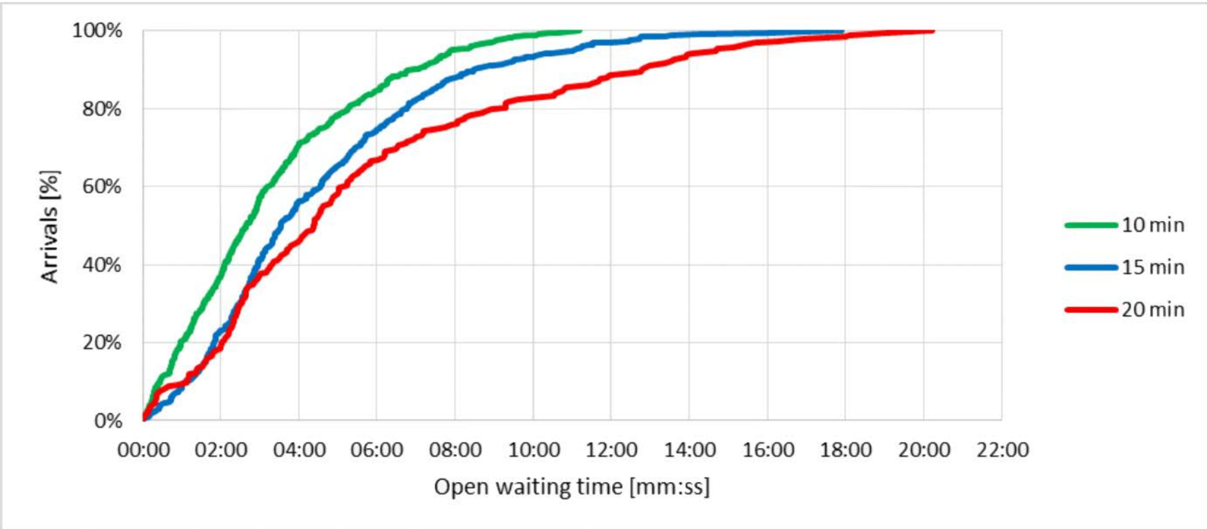
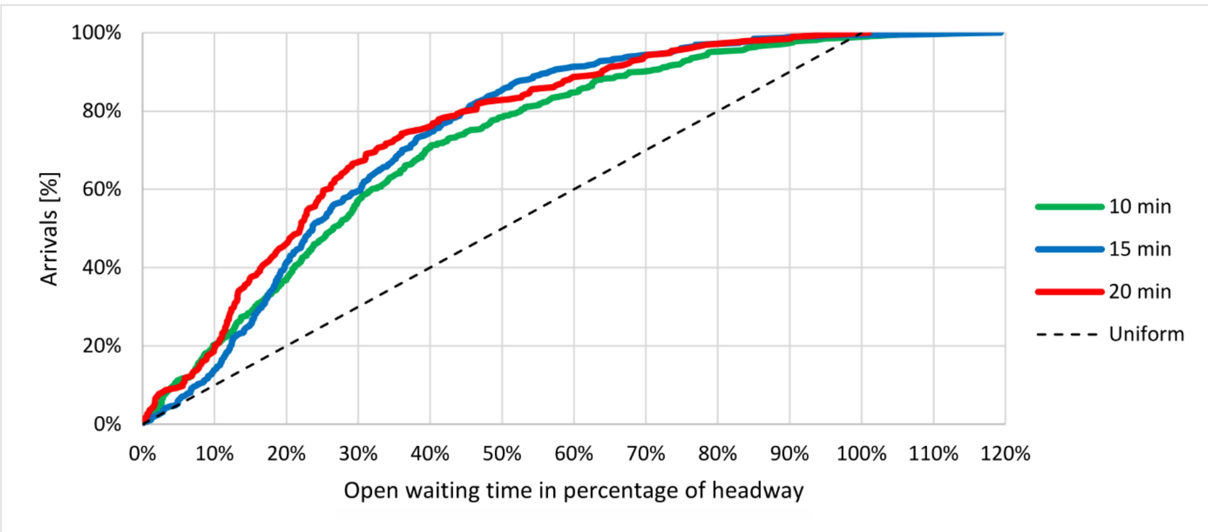


Figure 3: Cumulative arrival distribution at 10-, 15-, and 20-minute headways. The open waiting time is given in percentage of the headway.



Statistical tests were run for each headway to verify that the distributions are not uniform, using values from the observed vs a uniform waiting time. T-values of -45, -37 and -27, for the 10 minutes, 15 minutes and 20 minutes headways, respectively, clearly support that the distribution of observed waiting times are not uniform.

The results clearly show that the arrival distribution of public transport passengers is not uniform, as is assumed when waiting time is considered in transport models. The distribution shows that passengers tend to plan their arrival at the bus stop according to bus departure times to reduce their open waiting time. Moreover, this indicates that the waiting time used in transport models in low-frequency services is overestimated.

The arrival distributions for the three different headways show that more passengers choose longer waiting times at larger headways. This might be a consequence of passengers travelling with larger headways have budgeted for a larger buffer time to reduce the risk of not reaching their bus. The cost of waiting for the next bus (which will arrive in h minutes) will of course be higher for passengers that are travelling with larger headways. Hence, a lower share of random arrivals is expected at larger headways.

3.2 Is the time of arrival planned?

Knowing how the time of arrival is planned provides crucial information about passengers' waiting time strategy. This information is obtained by analyzing each arrival and calculating both the arrival time prior to bus departure (the open waiting time), and the arrival time prior to its scheduled departure time. Further, through knowing the length of these times, we are able to predict if the passengers planned their arrival based on using either the timetable or real-time travel information. This is because passengers who arrive solely based on information from timetables are not able to adjust their arrival in accordance with bus delays to avoid additional waiting time. We cannot say for certain (from analyzing these data) on which basis every passenger's time of arrival is based on, mainly because passengers can also arrive randomly. However, these results could be used to estimate the share of passengers who arrived at certain bases.

Figures 4, 5 and 6 show a two-dimensional diagram in which each dot represents one passenger's arrival at the bus stop. The arrival is plotted with an x-coordinate showing the open waiting time and a y-coordinate showing the length of time between the arrival and time for the next scheduled bus departure.

Figure 4: Arrivals at 10-minute headways. Time ahead of actual and planned bus departure.

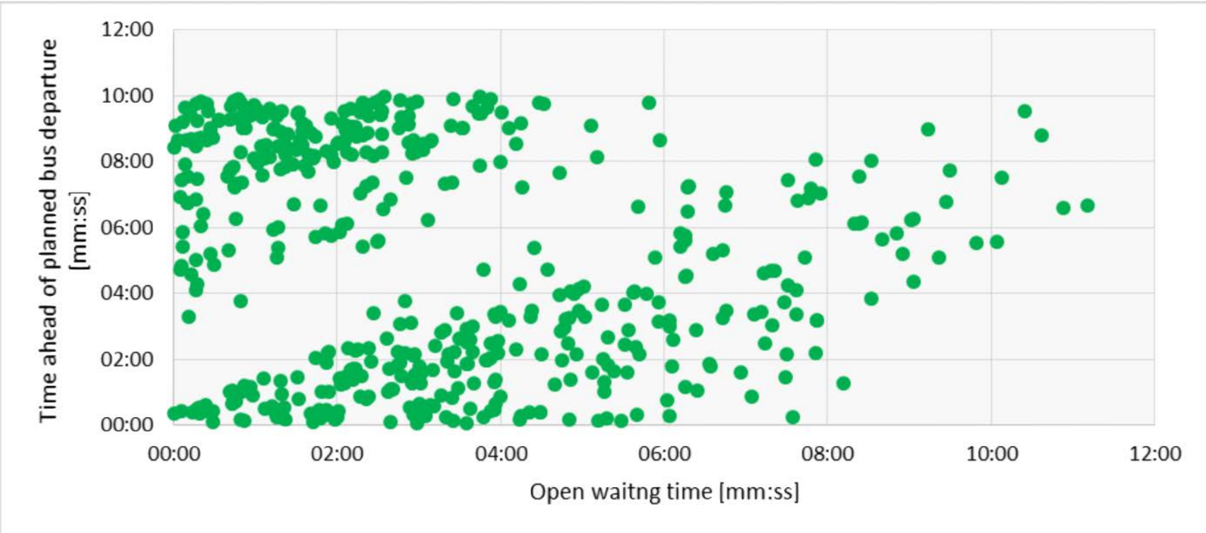


Figure 5: Arrivals at 15-minute headways. Time ahead of actual and planned bus departure.

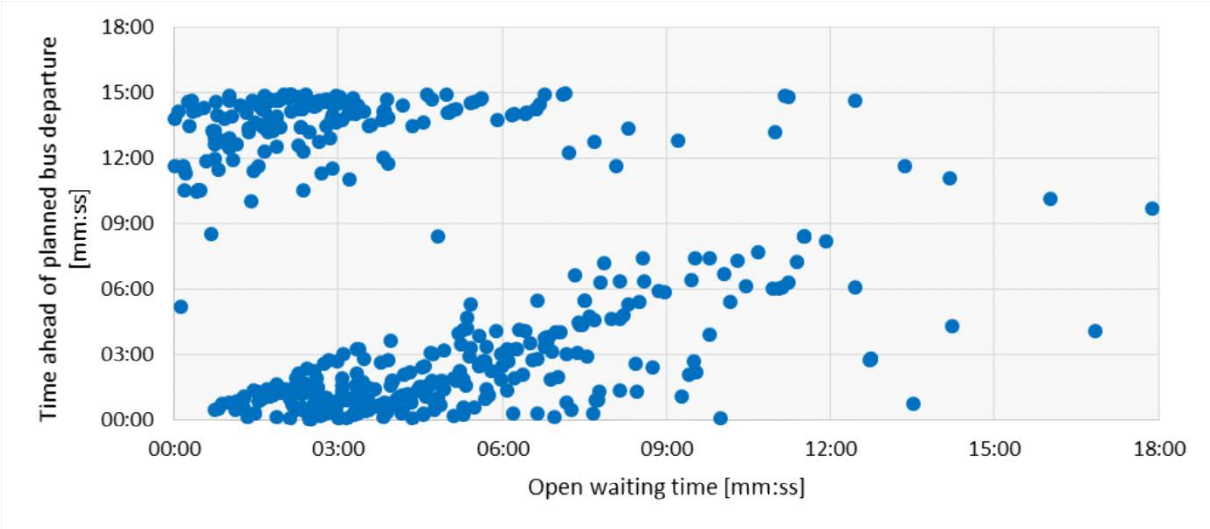
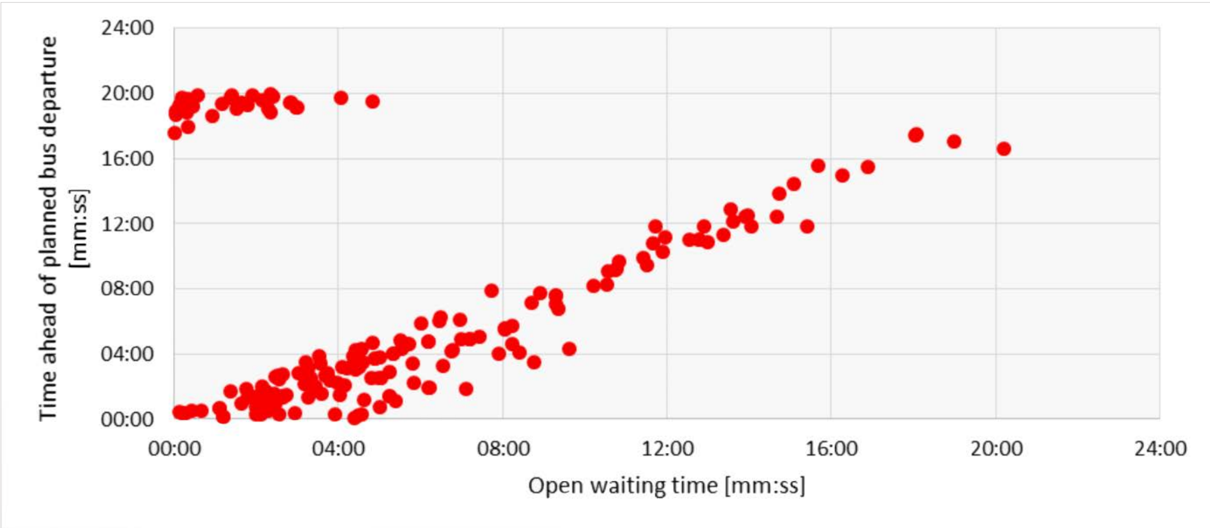


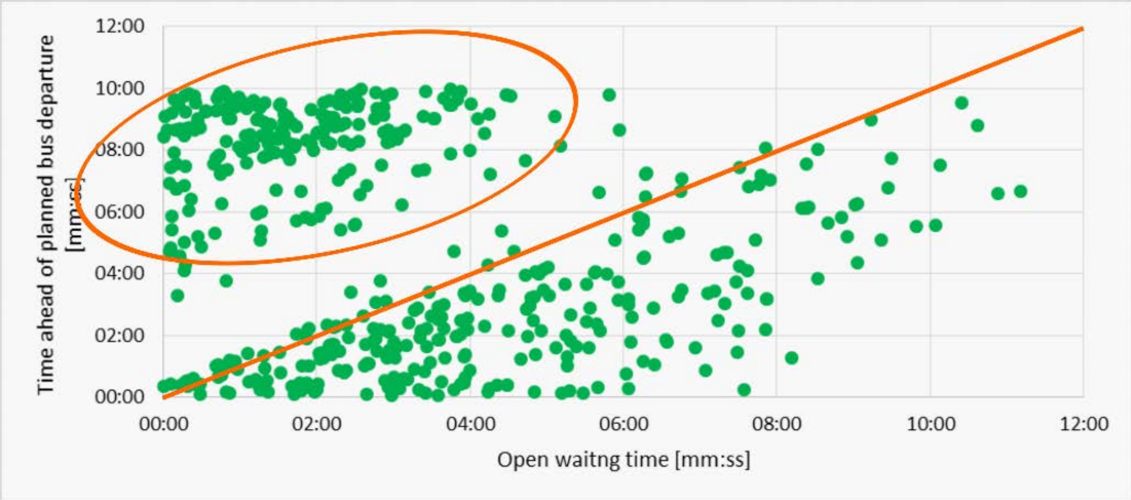
Figure 6: Arrivals at 20-minute headways. Time ahead of actual and planned bus departure.



The diagrams reveal that several passengers experience a shorter waiting time than expected if we assume that every bus departs at its scheduled time. Although these passengers arrive at the platform after the scheduled departure time, they still catch their bus because of delays. In the diagrams they are observed by their open waiting time being less than the time before the next scheduled departure. They therefore appear in the upper left corner above the imaginary line of x=y. These passengers may be aware of the delays and thus actively use some kind of information to reduce their open waiting time.

Through observing the same diagrams, it is possible to divide the passengers into groups according to their waiting time strategy, in this case their arrival time strategy. The grouping's objective is to create a foundation to provide improved estimates of the passengers' average waiting time, not to conclude which strategy they use. When reading the diagrams, we can see that the arrivals have centers of gravity in the upper left corner, and along and below the imaginary line of x=y. Hence, passengers can be divided into two groups. Figure 7 illustrates this point. Passengers who wait less than expected comprise the upper group, and passengers who probably plan their arrival based on the timetable comprise the lower group. Passengers who arrive randomly can be placed in both groups.

Figure 7: Passenger arrivals. Dividing passengers into two groups depending on their time of arrival.



The passengers in the upper group experience a shorter waiting time for one of three reasons: 1) they have arrived randomly at the bus stop, 2) they have traveled with the bus prior to the one they have planned to take due to significant bus delays, or 3) they have used real-time travel information to reduce their waiting time. Passengers who arrive after the scheduled departure time because they have assumed that the bus is delayed - but who do not use real-time travel information to confirm this - are categorized as random arrivals. Passengers who experience a shorter waiting time due to buses that depart earlier than scheduled are not included in this group.

The results indicate that the headway affects how passengers plan their arrival at the bus stop. The share of passengers who experience a shorter open waiting time than expected decreases with larger headways (Table 2). This finding indicates that the number of passengers who plan their arrival based on the timetable is greater at larger headways, which leads to a longer open waiting time. Moreover, delays have a greater effect on passengers traveling at larger headways than short ones.

Table 2: The share of passengers who experience a shorter open waiting time than expected.

Headways	N	The share of passengers who experience a shorter open waiting time than expected.
10-minute	494	46%
15-minute	457	38%
20-minute	194	17%

3.3 Delays

How the waiting time is affected by bus delays is crucial when waiting time is dealt with in the transport models. Results from this study, as shown in figure 8, show the average open waiting time for passengers at each headway as a function of delays. As expected, greater bus delays cause larger average open waiting times. However, the average open waiting time increases less than the corresponding bus delay. This shows the same as the figures in the previous section (figures 4-7); that some passengers experience a shorter waiting time than expected, are aware of the delays and have an arrival strategy that is not only based on the timetable.

Table 3 summarizes key statistics of the registered bus delays. All buses that depart one second or more after the scheduled departure time are defined as delayed.

Figure 8: Average open waiting time as a function of bus delays.

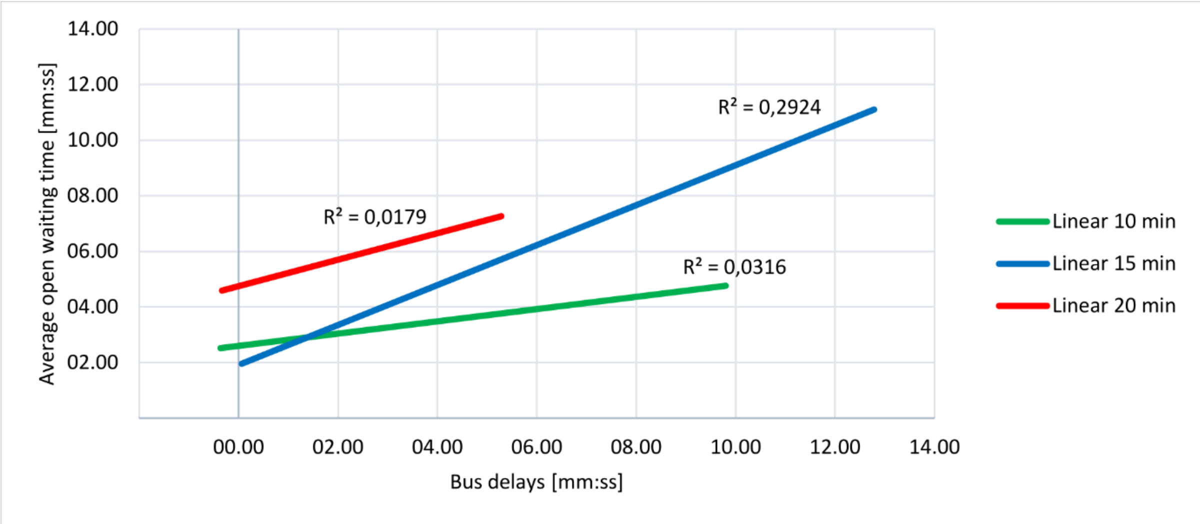


Table 3: Registered bus delays

Headway	N buses	% Delays	% Delays > 1 minute	Average delay	Max delay
10 minutes	131	95%	81%	02:43	09:48
15 minutes	96	100%	82%	03:19	12:47
20 minutes	94	92%	64%	01:25	05:17

Figure 8 shows a linear regression of average waiting time as a function of delays. The R-squared values are very low for 10- and 20-minute headways. This can be explained by that there are many random passenger arrivals and low bus regularity at 10-minute headways. At 20- minute headways most passengers experience short waiting times, but some experience very long, although the delays are small. The average waiting time can be described as W=a+b*delays, where a and b are either constant or a function of the headways. However, since the average waiting time at 15-minute headways differs from the two others, developing a universal expression from this data set is not appropriate.

Passengers unaware of delays experience longer open waiting times. Hence, there is reason to believe that passengers prefer to receive information about any delays to avoid additional waiting time. However, results from the survey indicate that slightly less than half the passengers take bus delays into account in their waiting time strategy, meaning that the majority arrive at the bus stop prior to the scheduled departure time, as if the bus always departs at the scheduled time. This is also confirmed by that less than half the passengers experience shorter waiting time than expected (see table 2).

Interestingly, the extent to which the use of real-time travel information is present, as well as how and if it is used to minimize the waiting time might be of great relevance. Results from the survey shows that about 1/3 of the passengers use real-time travel information, and it indicate that the use rises in correspondence with lower bus service regularity. This tendency is clearly shown in figure 4-6; At 10- and 15-minute headways, which is more unreliable and have larger delays than 20-minute headways, the arrivals are widely spread, and a large share of the passengers experience a shorter waiting time than expected. At 20-minute-headways the arrivals are largely centered around the two centers of gravity (figure 6), and a smaller share of passengers experience a shorter waiting time than expected. This indicates that the length of the delays, in addition to the regularity, has a major impact of whether real-time travel information is used. How this use affects waiting time in detail has yet to be clarified; nonetheless, it is expected that the average waiting time will decrease with increasing use. The study indicates that the passengers who use real-time travel information have neither the need or desire to include any buffer time, which will be explained in the next section.

3.4 Preferred waiting time

Since passengers plan their arrival according to bus departure times, we can assume that they have done so through including a certain amount of waiting. This can be interpreted to be a safety margin; the length of time they want to arrive before their bus departs. There is no reason to believe that passengers want to wait for a longer time than their desired buffer time; hence, it will be mentioned as the preferred waiting time. The length of preferred waiting time varies among passengers, ranging from zero up to several minutes.

The results show that only 10% of the passengers prefer to arrive less than one minute before their bus departs, which corresponds precisely with the observed open waiting times at 15- and 20-minute headways (figure 2). Despite longer waiting times at larger headways, no noteworthy differences in preferred waiting time for passengers at different headways have been found. The average of 2 minutes seems to apply to trips at all headways and for all travel purposes. The only factor that affects this value is the degree to which trips were planned and regular. Passengers who mostly ride the same bus (and thus have been able to create their own waiting time strategy) plan for a larger safety margin than those who do not have, or are not able to make use of, any strategy for a particular trip.

3.5 Time costs for waiting time

This study indicates that both the open waiting time and additional waiting time due to delays has a higher cost for the travelers than the hidden waiting time, as well as the other parts of a public transport trip. We did not ask the passengers about time costs because this is not the study's main objective. However, we did ask them a simpler question: *What part of the trip did you value the most? The least?* Table 4 shows the number of passengers (in percentages) who valued each part of the trip with lowest and highest time costs.

Table 4: Passengers' evaluation of the different waiting time stages

	Hidden waiting time	Open waiting time	Additional waiting time	Access time	Time onboard the bus, with a seat
Highest time cost	10%	30%	43%	2%	15%
Lowest time cost	23%	6%	5%	3%	64%

The results indicate that the time onboard has a higher cost for passengers travelling at larger headways, and that the cost for additional waiting time is higher for those who more often experience delays. Using this set of data, it is difficult to find any other correlations.

3.6 Other strategy elements

By varying the length of access time, passengers are able to determine the length of their open waiting time. This is often seen in the context of the following situations: If you are late for the bus, you are able to reduce your access time (e.g. by running instead of walking). This principle also works in the opposite manner, for example if you want to reduce your waiting time at the platform itself.

About 25% of passengers include variable access time in their waiting time strategy. On average, they are able to vary their access time by more than 4 minutes.

4 Discussion

Results given in this study shows passengers' open waiting time in low-frequency public transport services, as well as insights in their waiting time strategy. This basis could be used to suggest how the waiting time could be modeled in a way that provides improved approximations of real waiting time costs. Most of current models use the assumption of uniform passenger arrivals, and the average waiting time of W=h/2 then includes both the open and hidden waiting time. The registrations reveal the passengers' open waiting time, and results from the survey reveal if and how any other factors than the open waiting time affect passengers' total waiting time costs. Because the arrival distribution is far from uniform, and because many passengers plan their trips, no formula containing an element of 0,5E[h] is suitable for describing waiting time in low-frequency services.

4.1 Validity and representativeness

We can assume that results from this study will be representative for public transport services with low frequency in societies similar to the Norwegian one. However, the climate probably has a significant influence, which might lead to differences. The survey has shown that low temperatures, wind, and precipitation have a negative effect on passengers' perceived waiting time, which in turn increases the time cost. As the registrations were conducted during the winter season, there is reason to believe that most of the passengers made a greater effort to minimize their waiting time then, than they would during other seasons.

The study aimed solely at 1) passengers' first waiting time and 2) trips starting at home. This means that we cannot generalize the results to apply to all public transport trips because the possibility of planning the waiting time would be different. Nevertheless, the essence of the results (average waiting time is less than h/2) probably applies to all trips in low frequency services.

Next, it has been stated that W=h/2 is appropriate for small headways but not for large. However, the question about whether or not the location of random passenger arrivals is appropriate as well as the limit between small and large headways have not been discussed. Observations of passengers in Greater Manchester suggested that random passenger arrivals were valid on headways up to 12 minutes (Seddon and Day, 1974, found in McLeod, 2007), and the same general rule is used in Copenhagen (Nielsen, 2000). Results from our study show that the arrival distribution at 10-minute headways is far from uniformly distributed; thus, random arrivals are not valid here. We believe that the limit for when passengers arrive randomly and when they effectively use a strategy to reduce their waiting time is lower now than before - and might become even lower in the future. This situation might be explained by changes taking place in society, where our everyday lives are very time-conscious. Nevertheless, societal changes also bring about technological advances that introduce the possibilities for new waiting time-reducing strategies, e.g. real-time travel information. Because we only investigated headways as low as 10 minutes, we can only assert that the limit is lower than 10 minutes, but we cannot assert exactly where this limit is. It is probably much lower than 10 minutes because the arrival distribution at 10-minute headways is far from uniform and because most passengers do not want to face more waiting time than necessary.

4.2 Waiting time, hidden waiting time, and time costs

Modelling the waiting time for public transport passengers is not easy. In everyday speech, the waiting time is referred to as 'time spent waiting at a bus stop'. However, this time is not sufficient to include all the inconveniences related to waiting time that passengers experience when traveling by public transport. Because passengers cannot travel whenever they want, hidden waiting time may be present, and the transport models have intended to include these inconveniences by defining the entire waiting time as half the time between departures. This is an adequate representation of travel costs in conjunction with waiting time in high-frequency services where random arrivals are present. However, at larger headways the models will compute a much higher waiting time cost than passengers experience in real life because they adapt to the time table, and largely uses a waiting time strategy to reduce their waiting time. Even though the waiting time cost pr. minute decreases as the waiting time increases (Samstad et al., 2010), the total waiting time cost will still be overestimated.

One solution on how to model the waiting time is to divide the waiting time into different stages based on the waiting time's form, in turn discovering the duration and the time costs of each stage. Dividing into hidden-, open-, and additional waiting time due to delays seems to be appropriate.

Waiting time at public transport trips usually splits into hidden and open waiting time. However, waiting time is not separated in current transport models, being described by W=h/2. Considering that both the preferred open waiting time and actual open waiting time are approximately the same for passengers at all headways (Ruud et al, 2010), it is in fact the hidden waiting time alone that causes the overestimation of waiting time costs at large headways. However, what is hidden waiting time, and is it present at all public transport trips?

It is often asserted that hidden waiting time is solely dependent on the headway. However, the hidden waiting time will only be present at the origin if there is time between the point of time you want to travel and the point of time the trip starts, because you are not able to travel whenever you want. (It can also be present at the trip's destination, but this is not covered in this study.) When a passenger knows the bus departure time, and starts the trip in accordance with this knowledge, the hidden waiting time at the start of the trip will be non-existent in many situations. In addition, in most situations when a passenger encounters hidden waiting time, he is able to convert this into longer open waiting time and even access time, resulting in a low number of passengers who experience a considerable hidden waiting time.

When considered from this angle, and because it is difficult to measure the duration of hidden waiting time each passenger experiences (and, even worse, giving it a time cost), other methods should be considered for calculating the total waiting time costs at different headways.

There is reason to believe that additional waiting time at the platform due to bus delays has a higher time cost than the planned open waiting time. This is because passengers might not have budgeted for this waiting time, and it can also cause other inconveniences beyond the journey itself. A study conducted in Oslo and its suburbs (Ruud et al., 2010) has found that the time cost associated with delays is more than three times higher than for waiting time. However, this value does not state at which point of the journey the delays occur. It might be that this time cost will not be the same whether you are on the bus itself or merely waiting at the platform. In addition, the waiting time in the same study is defined as half the time between departures, which does not reflect the true cost of open waiting time.

Our study indicates only a slight difference between open waiting time and additional waiting time with respect to what has the highest time costs. Perhaps these questions were formulated poorly to the extent that the passengers did not understand the difference between these two options. However, because the cost of delays is assumed to be much higher than for the open waiting time and the fact that there were more passengers who valued additional waiting time the most, further investigation into this topic is recommended.

4.3 Delays and strategies

The extent to which the use of real-time travel information is present might be important to provide a closer approximation of real travel costs in the transport models. This is seen in the context of that passengers should be divided into groups according to which waiting time strategy they use, and thereafter the duration of their waiting time. An appropriate grouping consists of three groups; 1) random arrivals, 2) arrivals based on timetables, and 3) arrivals based on use of real-time travel information. It is reasonable to believe that passengers using real-time travel information are those who aim for and are experiencing the shortest waiting time, and that their waiting time is least affected by bus delays. Passengers using the timetable are expected to arrive a few minutes ahead of the scheduled departure, and are vulnerable to delays. The grouping's objective is to create a foundation that provides improved estimates on passengers' average waiting time. Hence, it should be based on their arrival in accordance with the actual and scheduled bus departure time (like in figure 7), and not which strategy each individual actually used.

The arrival registrations are performed on passengers' first waiting time for trips starting at home. It is expected that most of the registered passengers are frequent public transport users that have different travel behavior than occasional users (Carrasco, 2012, found in Parbo et al, 2016). Frequent users are more likely to make use of a waiting time strategy and plan their trip. Probably, it is most likely on trips starting at home that passengers have the greatest opportunity to plan their waiting time. On other trips, e.g. when travelling home in the afternoon, it is probably more difficult for many passengers to start their trip at the exact same time every day, which of course affects their waiting time strategy and waiting time.

It is reasonable to believe that the costs for the open waiting time are greater during the cold Norwegian winter, which was present when these registrations were conducted. A total of 18% of the passengers in this study answer that the inconveniences of waiting time are larger during bad or cold weather (63% among those who answered that the inconveniences were not always the same). If the time cost for waiting is higher, it may be that passengers are extra attentive about reducing the length of the open waiting time during such poor weather conditions, leading to the situation where the observed waiting times in this study might be shorter than if the study had been conducted during a different season. The extent of passengers using variable access time in their strategy might also be higher during other seasons for the same reasons.

Increased use of real-time travel information will probably lead to shorter waiting times. Results from this study show shorter average waiting times than in a study conducted in Oslo only 6 years ago, where the average was found to be around 5-6 minutes for all headways (Ruud et al., 2010). It is quite likely that the increased use of real-time travel information might be one of the reasons for this decrease. Moreover, the waiting time costs for public transport passengers will probably decrease even more over the course of the next few years.

4.4 Further research and how to better model waiting time

Future transport models should be based on dividing public transport passengers into three groups depending on their waiting time strategy: 1) random arrivals, 2) arrivals based on the timetable, 3) arrivals based on the use of real-time travel information. An expression for the average waiting time among the passengers in each group, which includes delays and headways, should be developed. These formulas are intended to replace W=h/2. Alternatively, waiting time curves (like those in figure 2-4) can be made. The next step is to apportion the passengers into the three groups. The grouping should not be static, because passengers' waiting time strategy might differ between different travel purposes, time of day, headway, and more. With this method we have a much closer approximation to how long the passengers actually wait, and we have a method that easily could adapt to several situations where the waiting time and waiting time strategies is expected to be different. In turn this could be used to provides closer approximations of the real travel costs for all public transport trips in low-frequency services.

5 Conclusion

There is clear evidence that passengers plan their arrival at bus stops to reduce their waiting time when travelling by public transport in low-frequency services. The average open waiting time is less than half the time between departures, and the hidden waiting time is probably considerably less than previously expected. This indicates that the waiting time used in today's transport models is overestimated. The average open waiting time is found to be 0.32*h at 10-minute headways, 0,29*h at 15-minute-, and 0,28*h at 20-minute headways.

Passengers are largely using an arrival strategy. The conventional strategy to reduce the open waiting time is to arrive at the bus stop shortly before the scheduled bus departure. However, this strategy is vulnerable for delays and will not necessarily lead to shorter waiting time. Therefore, a large portion of passengers use a strategy which deals with delays and irregular bus departures. Such a strategy is often based on past experiences, real-time travel information or both. Nevertheless, it is only the use of real-time travel information that can safeguard passengers to rarely wait longer than desired and what they have budgeted for. Through an ever-increasing use of this technology, the average waiting time is expected to decrease, which leads to an even greater need for new methods of dealing with waiting time in future transport models.

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